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Investigations on effectiveness of embedded PZT patches at varying orientations for monitoring concrete hydration using EMI technique

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HIGHLIGHTS

- Orientation study on embedded PZT patches.
- Hydration monitoring in real life RC beam.
- Inclined PZT patches does not work effectively.

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ABSTRACT

The electro-mechanical impedance (EMI) technique has already been established to be an effective technique for detecting incipient damages in engineering structures including reinforced concrete (RC) using smart piezo-electric sensors. Its effectiveness in monitoring the hydration of concrete, using surface bonded and embedded lead zirconium titanate (PZT) patches has also been investigated well. However, the influence of patch orientation while embedding them in concrete is still unexplored. The present study investigates the effectiveness of the EMI technique using PZT patches embedded at different orientations (here, 0°, 45° and 90°) with the axis of the structure, while monitoring the hydration of a real-life prototype RC beam. Further, the effectiveness of the PZT patches in monitoring the strength gain in concrete is investigated. It is observed that the PZT patch placed in the inclined orientation (45°) least efficient in capturing the progressive changes of hydration in the concrete in comparison to the other two orientations. The EMI technique showed best results when PZT patch was placed in horizontal position (0°) with the longitudinal axis of the beam.

1. Introduction

For the last two decades, the electro-mechanical impedance (EMI) technique using smart piezoelectric sensors is being investigated for its possible applications in monitoring civil structures [1–4]. The EMI technique has been successfully demonstrated suitable for health monitoring of concrete in surface-bonded and embedded configurations [5,6]. The EMI technique involves acquisition of conductance (the real part) response over a frequency range of vibration from piezoelectric ceramic lead zirconium titanate (PZT) patch, either surface bonded or embedded inside the structure to be monitored. The variation in the conductance and susceptance (the imaginary part) of the admittance response plotted with the vibration frequency is known as the EMI signature. Any damage in the host structure is reflected in the EMI signature making it different from the signature originally acquired in the pristine state. The root mean square deviation (RMSD) percentage is generally calculated to quantify these changes statistically and is given by Eq. (1) [7,8]

$$RMSD\,(\%) = \sqrt{\frac{\sum_{i=1}^{N}(G_i^1 - G_i^0)^2}{\sum_{i=1}^{N}(G_i^0)^2}} \times 100 \tag{1}$$

where G_i^0 is the baseline conductance value and G_i^1 is the post-damage conductance value at a same measuring frequency. The RMSD values can also be presented in sub-frequency interval approach, in which the signature is compared to the base line signature separately for different frequency ranges [4,9,10].

Besides monitoring the damage, the monitoring of concrete hydration while construction is an important aspect of SHM of

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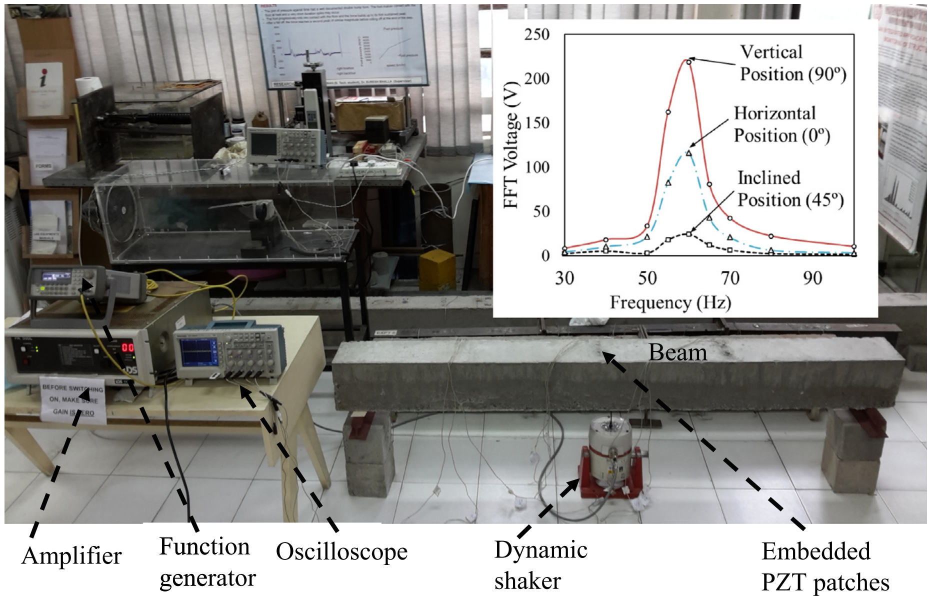

Fig. 1. Experimental setup for measuring voltage response on dynamic excitation. Insight: Comparison of FFT Voltages with different excitation frequencies for different PZT positions [18].

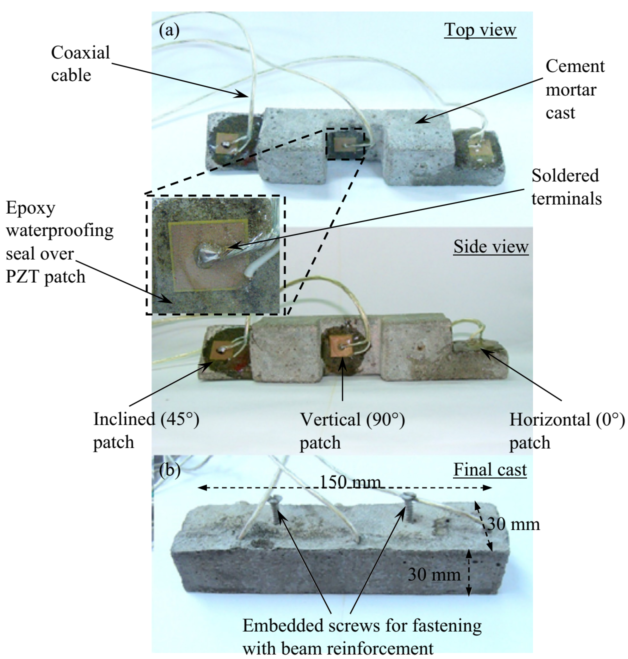

Fig. 2. PZT patches (a) bonded on the cement mortar casting (b) embedded completely in the cuboid mortar cast.

RC structures. Researchers have traditionally employed ultrasonic techniques to monitor the hydration process. These processes have limitations like hindrance due to the presence of framework between concrete and the transducers and lack of accessibility of the concrete members like beams [11,12]. Whereas, the EMI technique for hydration monitoring do not suffer from such constraints. Shin and Oh [13] found EMI signatures to be very sensitive towards the strength gain of concrete during hydration. They reported a rightward shifting of resonance peak in EMI response at 200 kHz of frequency with increase in the curing time. Shin et al. [14] conducted a series of experiments using surface bonded PZT patches and found that with increase in the strength of concrete, its mechanical impedance changes, which is directly reflected in the conductance signature. They reported a similar downward and rightward shift in the resonance peak with increase in the curing time. Bahador and Yang [15] used aluminum

Table 2
Properties of RC Beam.

Properties of RC Beam	Value
Length (L)	2000 mm
Cross Section	210 mm × 150 mm
Flexural rigidity (EI)	3.9×10^6N m^2
Mass per unit length (m)	84 kg/m
Characteristic strength of concrete (f_{ck})	35 N/mm^2

Table 1
Technical details of PIC-151 [19] and epoxy [20].

Property		PIC 151	Epoxy
Density	(ρ)	7800 kg/m^3	1200 kg/m^3
Relative permittivity	($\varepsilon_{33}/\varepsilon_0$)	2400	–
	(($\varepsilon_{11}/\varepsilon_0$)	1980	–
Dielectric loss factor	(tan δ)	0.02	–
Piezoelectric strain coefficient	(d_{31})	-2.1×10^{-10} m/V	–
	(d_{33})	5.0×10^{-10} m/V	–
Elastic compliance coefficient	(S_{11}^E)	1.5×10^{-11} m^2/N	–
	(S_{33}^E)	1.9×10^{-11} m^2/N	–
Young's modulus	(Y^E)	6.9×10^{10}N/m^2	9.79×10^8N/m^2