

Identification of Strength Gain of Precast Concrete during Initial Period using Reusable PZT

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ABSTRACT: The use of precast concrete structural elements is increasing immensely in the construction industry. It is a requirement to monitor strength gain or health of concrete during the initial period to get optimum quality during the construction process. Furthermore, optimal time for demoulding and transportation of precast element is important for concrete suppliers. It can provide the correct information for the next phase to progress safely. There is a need to check the strength and quality of the precast structural elements. In this context, this research proposes impedance based non destructive curing strength monitoring method. The recent advances and innovations in the recent times have fascinated many researches to develop new non destructive techniques based on Electro-Mechanical Impedance (EMI) approach. It is used to measure the impedance signal of concrete mass. Lead Zirconate Titanate (PZT) Transducers have been used for the identification of the parameters. In this work, a reusable transducer setup to monitor the structural health is developed and it illustrates new technology of reusable PZT patches. The results show that the reusable setup is able to effectively monitor strength gain of precast concrete and the structural changes along with surface bonded PZT. It can also be detached from the precast concrete for further re-use.

KEYWORDS: Electro-Mechanical Impedance(EMI); Structural Health Monitoring(SHM); Reusable; PZT; Concrete; Precast

1. INTRODUCTION

The application of Precast Concrete Structural Systems has been attaining tremendous progress worldwide. This is because precast structural elements have several benefits in comparison with monolithic construction such as quality control, speedy construction, and suitable application to regularly modular system. Recently, there has been increasing demand for large structures such as high rise building. Therefore the concrete material, especially precast elements, has been more frequently used in construction. It is well known that each and every structure is designed for a specific lifetime, which can vary from a few years to a century. In addition, monitoring of the initial strength is important for reducing the construction time and cost because it can determine the appropriate curing time to achieve sufficient strength to progress to the next phases namely transportation, commissioning, etc safely. To ensure the safety of the structure, different destructive and non-destructive techniques are used. The in situ strength of concrete structures can be determined with high precision by performing strength testing and material analysis on core samples removed from the structure [1]. However this method can destroy the concrete structure.

The advent of smart materials, such as piezoelectric materials, shape-memory alloys, and optical fibers, has attracted interests among researchers and engineers to develop new nondestructive monitoring techniques. The key advantage of using these materials as sensing devices is that they can be placed anywhere even in remote and inaccessible locations to monitor concrete structures. In particular, the Electro-Mechanical Impedance (EMI) sensing technique which employs piezoelectric transducers has been successfully emerged as a very promising technique for the strength development monitoring of concrete at initial condition [2].

Traditionally, structural inspection was carried out by trained or experienced experts. The effectiveness of such inspection are costly and can only identify macroscopic damages at accessible locations. For this purpose numerous

structural engineers have drawn attention towards using modern sensor technology for making structures, smart enough to warn the concerned authorities before their failure. Structural Health Monitoring (SHM) is a new engineering discipline, which deals with the continuous monitoring of the structures for incipient to severe damages

Based on the EMI Technique, surface bonded PZT transducers have been widely used for parameter identification for various engineering structures[3-10].As new materials and technologies are discovered, buildings get taller; bridges get longer spans and the designs of structures become more ambitious, but more complex. In view of these developments, there is an increased requirement to provide both the costs savings with regard to maintenance and a safer environment for preventing structural failures. The idea of reusable EMI method is still relatively new, resulting in the reduction of monitoring costs since the same piezoelectric material is used as many times as possible, while ensuring better repeatability and reliability in measurements. It was found that the buried Transducers though sensitive enough for localized monitoring, the wire connection can be easily damaged during casting. For repetitive application such as in precast industry, a method to reuse the PZT transducer was found necessary. The research about reusable PZT patch is limited. The feasibility of reused PZT transducer setups was first investigated by Yang et al. [11, 12] using a piece of PZTbonded to a piece of aluminum or plastic enclosure with two bolts tightened inside some holes drilled in the enclosure. In this present paper, Objective was to extend Study of Tawie and Lee[13] to develop a device using a nut and a bolt where a PZT material was attached on the head of the bolt for the EMI method.

Statistical technique such as Root Mean Square Deviation (RMSD) have been used to associate the damage or material changes with changes in the signature

$$\text{RMSD (\%)} = \sqrt{\frac{\sum (G_2 - G_1)^2}{\sum G_1^2}} \times 100(\%)$$

Where,

G1= Baseline signature of PZT conductance

G2 = Corresponding conductance at each monitoring time

II. SYSTEM DEVELOPMENT

In order to perform structural health monitoring of concrete structures using EMI technique, a model precast beam and reusable setup was cast. The experimental investigation is carried for damage identification and crack detection. The instrument used is digital impedance analyzer (LCR meter E4980A) of frequency range of 20 Hz to 2 MHz and its connecting fixture, and a USB cable and VEE Pro 9.32 for data acquisition system.

This experiment essentially involves a precast beam with reusable setup and surface bonded PZT. The instrument required to obtain signatures are digital Impedance Analyzer (LCR meter E4980A) and its connecting fixture and a USB cable and VEE Pro 9.32 for data acquisition. This test was performed for healthy condition of the beam. High frequency PZT patches were used to perform the test. The properties of high frequency PZT are as shown in Table 1

Table 1: Material Properties of PZT

Material Properties	Dielectric Constant	K_3^t	3200
	Coupling Coefficient	K_p	0.65
	Piezoelectric Charge Constant (10^{-12} C/N)	d_{33}	580
	Dissipation factor(at 1 KHz)	$\tan \delta$	0.02

The soldered PZT patch in the form of reusable setup was wired to impedance analyzer through connecting fixture of LCR meter. Then the frequency was swept through 10 kHz to 400 kHz i.e. the PZT patch transfers this vibrations to the structure through adhesive bond layer. These vibrations are transferred to structures and reflected back from the same PZT patch through waves, which will indicate the health of the structure. Similar procedure is adopted for reusable PZT patch. The required parameter i.e. Conductance (G) is directly measured through LCR meter for all the values of frequency. From the obtained data, the graph of Conductance Vs Frequency is plotted. These graphs are said to be the Conductance Signature or just a signature shown by particular sensor for specimen. This data is saved in excel format

and can be available as and when required.

The Precast Concrete Beam having dimension of 3000mm x 300 mm x 380 mm was the Specimen under Consideration. For Experimental purpose, the dimension is scaled for 1:3. Therefore the dimension of Beam for Experimentation purpose = 1000mm x 100mm x 125mm.

In order to construct the beam of size of experimental dimension a steel mould was prepared having holes on either ends so that Reinforcement could come out of beam and attached accordingly on the site. Fig. 1 shows the Formwork and Reinforcement of the Specimen



Fig. 1 : Reinforcement and FormWork Details of Specimen

The reusable setup consists of a Nut , Bolt , PZT and coaxial wire. In this case nut is embedded in specimen while casting of specimen. The PZT patch is attached onto the bolt. The bolt with PZT patch is connected followed by coaxial wire. The nut can be removed from the specimen and again re-used for different specimens. Fig. 2 shows Nut and Bolt reusable Setup arrangement.



Fig.2: Nut and Bolt Reusable Setup

The surface bonded PZT was attached on the surface of the precast beam. To prepare the reusable setup the surface of naked PZT patch with the dimensions of 10mm×10mm×0.2mm were soldered to coaxial cable wires and attached on the reusable setup, therefore it can be used multiple times.

The quantity of material required for casting the specimen like fine aggregate, coarse aggregate, cement and water are calculated by concrete mix design. Table 2 shows the material properties and dimensions of precast beam.

Table 2: Material properties and dimensions of Precast beam

Dimension /Properties	Value
Length (L)	1000 mm
Cross-Section	100mm x 125mm
Grade of cement(OPC)	53
Grade of Steel	Fe 415
Reinforcement Bars	2#8mm dia @ top and Bottom
Stirrups	6mm dia @ 90mm C/C

The precast beam is casted based on the above properties as given in Table 2. On the given Beam, 2 PZT patches are attached, out of which 1 is reusable setup other is Surface Bonded PZT. The PZT patches are adhered with Araldite to form a Bond Between precast Beam and PZT Patch. The reusable setup is made of nut and bolt reusable setup. The assembly for the experiment of PZT patches is as shown in Fig. 3



Fig 3: Surface Bonded PZT and Resuable PZT on Precast Beam

III. RESULTS AND DISCUSSION

The healthy structure response is taken, with the reusable setup in the precast concrete beam. Piezoelectric patch was connected via cable to LCR meter and corresponding response was recorded. The beam was subjected to frequency range of 10 to 400 kHz. In this range, corresponding conductance values were recorded by LCR meter. The same procedure is carried out for PZT surface bonded and corresponding responses measured. The conductance graphs are then plotted and all these plots are shown in respective Fig.3 and Fig.4. Fig. 3 represents Conductance Signature obtained from Surface Bonded PZT whereas Fig.4 represents Conductance Signature obtained from reusable setup.

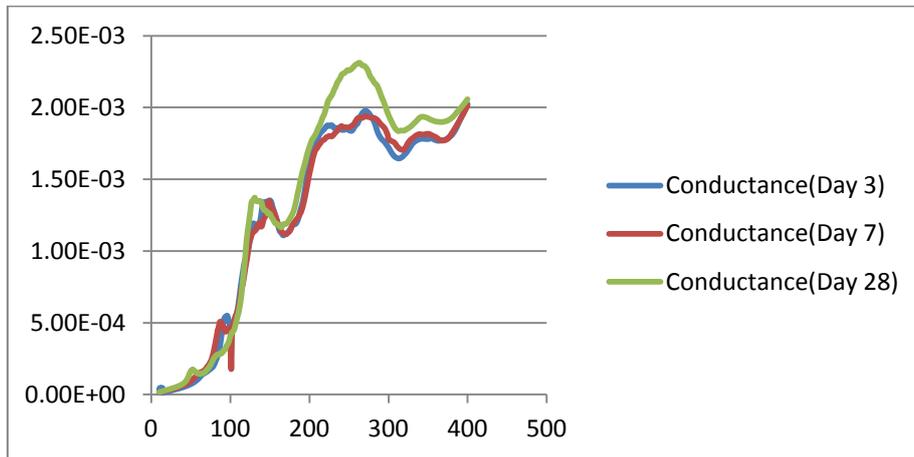


Fig 3 : Conductance Signature Obtained from Surface Bonded PZT

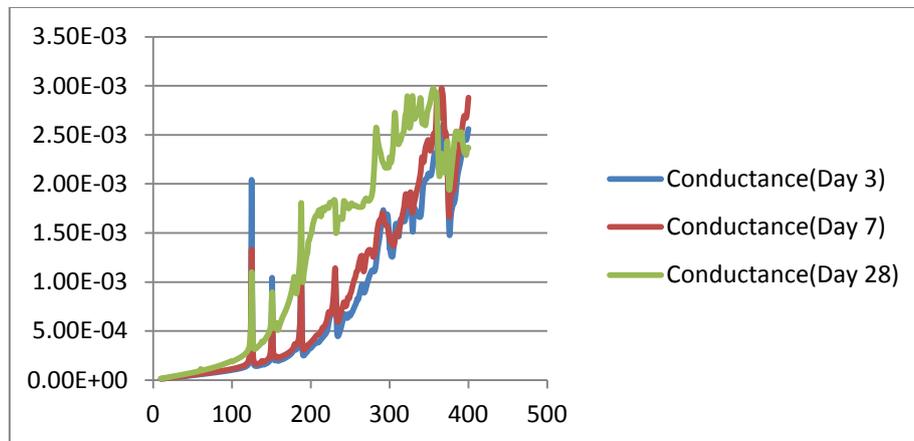


Fig 4 : Conductance Signature Obtained from ReusableSetup

There was variation observed in conductance response of precast beam as day proceeded, as all parameters were constant, it is due to increase in strength with every passing day. Alternatively, Stiffness of the beam went on increasing day by day. This can be seen in Fig.3 and Fig.4. This variation in conductance was calculated by using RMSD method. The RMSD recorded for Day 7 and Day 28 were 3.78% and 12.3% respectively for Surface Bonded PZT whereas the RMSD recorded for Day 7 and Day 28 were 10.7% and 37.9% respectively for ReusableSetup. Fig. 5 shows RMSD for Precast Beam by Surface Bonded and ReusableSetup (Day 7 and Day 28)

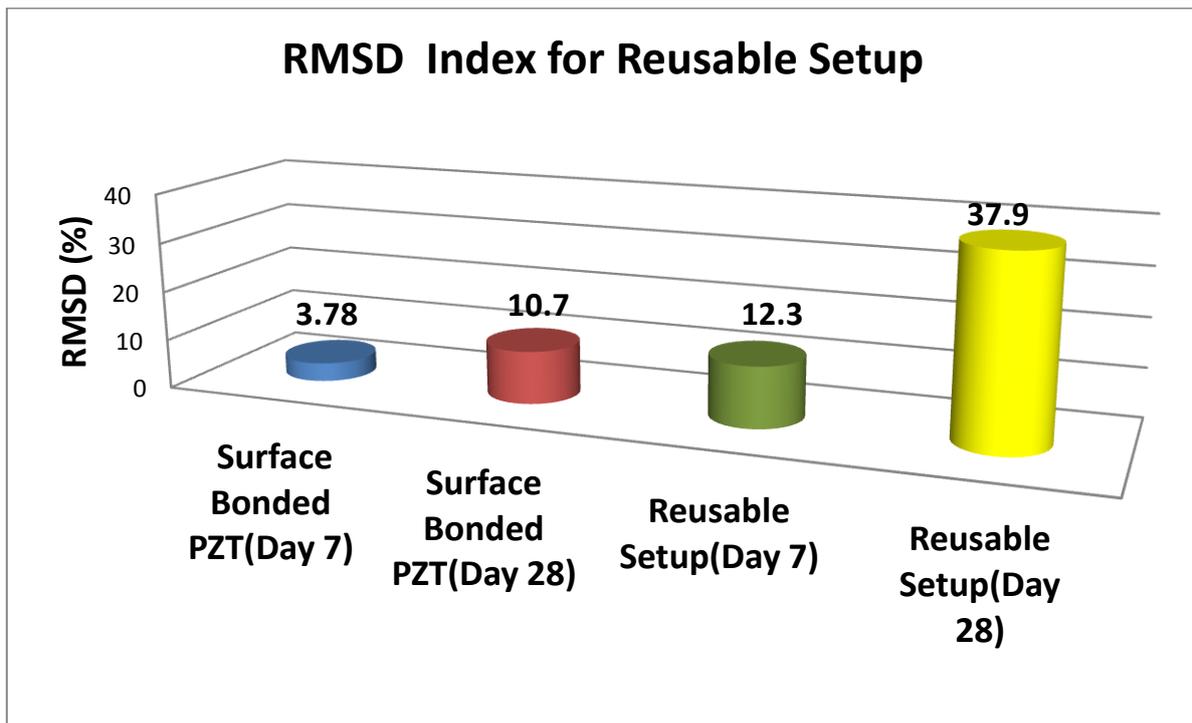


Fig 5 : RMSD for Precast Beam by Surface Bonded and Reusable Setup (Day 7 and Day 28)

It was observed that, change in signature recorded by reusable setup is more as compared to surface bonded PZT. The change in the conductance signature was quantified by using RMSD Index

IV. CONCLUSION

In this paper, research using reusable setup as well as surface bonded sensing approach is applied for initial strength gain of concrete. Both the reusable setup and the Surface bonded PZT transducer developed in this study effectively monitor the initial strength of concrete. The reusable PZT transducer shows higher sensitivity for monitoring the strength and stiffness compared to surface bonded PZT. Moreover the reusable PZT transducers are more favorable since the PZT transducers are expensive compared to concrete material. The device can be easily reused for many times as it can be detached and attached again and again. The tests conducted established effectiveness, ease, along with economy of the reusable PZT patches developed.

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