Non-destructive evaluation of a steel plate subjected to mechanical damage

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Abstract. Advent of smart materials in the non-destructive evaluation (NDE) techniques in recent times is steadily cementing its way into structural health monitoring (SHM) of steel structures. To evaluate the performance of the sensor (namely piezo transducer) being used as an integrated sensor into a metal plate in making it a self-sensing smart metal plate is the main objective of the present study. The performance of such a sensor is studied against the parameters such as variation in temperature, incremental mechanical damage and circular lineament. For practical application purpose of such a technique, the parameters under consideration need to be effective over desired range, hence, temperature variation is opted from 50˚ C to 150˚ C along with damage level ranging from zero to 75mm which covers elementary level (i.e. 10mm aperture) to acute level (i.e. 80mm aperture). The sensor was found to be sensitive to damage, through standardisation root-mean-square-deviation of around 8-15% occurring per ˚C change in temperature along with a maximum damage of 458.8% RMSD at acute damage levels. Furthermore, the transducer had good sensing range and was able to detect the change in mechanical properties of the material even at the distance of 750mm from the sensor placement location. Keywords: steel plate, non-destructive evaluation, sensors, damage, temperature

1. Introduction
Steel is an important and expensive construction material that plays an important role in the modern fast-track construction [1-18]. Steel structures are more often subjected to vibrations, impact loading, earthquake loads etc., (leading to extreme stresses and deflections) among several damages during its life time [19-20]. Many techniques have been used in the recent past for health monitoring of steel structures however there have been very few studies solely dedicated to integrating these sensors into the structural member itself as opposed to using the sensor at the time of condition assessment [21-23]. Several benefits arise when using sensor integrated with the host structure such as, saving time of sensor installation, continuous data collection, health assessment in inaccessible locations of the structure etc. There has been as rise in non-bonded configurations of piezo based sensors in the recent past, although it is an economical method of data acquisition, it is not easy to plant and remove the sensor at difficult locations. Hence, the main application of integrating the sensor into the structure would be easy in accessing such locations through extended soldered wires. A 2D metal plate selected for the present study was of circular disk type piezo sensor (CPS) as shown in Figure 1. Temperature testing was carried out for the same as mentioned above. A similar metal plate was chosen and the damage level studies were carried out.

2. Smart materials and techniques
Currently, there have been many smart materials used for NDE and SHM like rheological fluids, shape memory fluids, magnetostrictive materials, optical fibers etc. In this study a particular type of smart material known as piezoelectric ceramic, lead-zirconate-titanate (PZT) was used. The special property of this material being that it develops charges when subjected to external stress and undergoes strain when applied with external electric field.
Figure 1. 2D diagram of ring type piezoelectric transducer

3. Novel design proposal
The new design proposal involves using a steel plate drilling in between to fit the circular PZT patch. The surface was cleaned and prepared after the drilling with ethyl alcohol. After the PZT was placed in position, electrodes were soldered on both sides and then allowed to cool. A five-minute epoxy was used to seal the PZT patch in place and also to protect it from the effect of damage and inherent vibration during drilling. The epoxy coating was applied on both sides and allowed to cure for 5 to 10 minutes. The components used are shown in the Figure 2.

Figure 2. Components of new design

Figure 3. Damage level proposed for sensitivity analysis of EBSP

The damage level is gradually induced by drilling holes using a drilling machine. The damage was proposed to be induced in different levels. The damage state at level zero or no damage is called as pristine state. The level 1 damage is called as elementary level whereas level 8 is named as acute damage level. The damage was created in an anti-clockwise manner around the PZT patch as shown in Figure 3.
4. Experimental Facility
The hot-oven facility for curing of concrete specimens was used for this test. The least count on this machine was 1°C and the temperature adopted was from a minimum of 50°C and a maximum of 150°C. The sensor data was extracted through an LCR meter in the range 150kHz to 250kHz. To avoid temperature drop in the specimen after removal from the oven to extract data a smaller frequency range was used. The methodology used for the sensor data analysis is illustrated through flow chart as shown in Figure 4.

5. Results and observations
Against the level of mechanical damage, the conductance signature variation recorded by self-sensing smart metal plate is shown Figure 5. It can clearly be seen that with change in mechanical damage level there exists a gradual shift in signatures. In the range of 180kHz to 250kHz the change is clearly visible as seen in the above cited Figure 5.

The shift in peak frequencies can be observed and shows increase in damage. Although visually a damage indication can be visualised the value of the shifts needs to be estimated. For this purpose, root-mean-square deviation (RMSD) which is a statistical parameter is used. The RMSD variation in the specimens in general and normalised forms are shown in Figure 6 and Figure 7, respectively.
Normalised RMSD was calculated from 0-150%. A sharp rise in RMSD values was seen for temperature change from 50-90˚C and these values remained nearly constant for change of temperature from 100-120˚C. It can also be noticed that RMSD corresponding to damage levels from 3 to 4 as well as from 5 to 6 are respectively constant. A spike in values is seen against both 7th and 8th damage levels respectively.
6. Conclusion
The major contributions and conclusion of the present study is summarised below,

- The integration of sensor with the host structure may be possible if done carefully and is easier to acquire data in comparison with its non-bonded counterparts.
- The sensor placed was successful in detecting damage from elementary to acute levels which is evident from the RMSD plots.
- The effect of temperature was found to be profound in the range 50-90°C, it is recommended that temperature compensation be carried out.
- Parametric study is to be carried to completely understand the performance of the sensor integration. But as a preliminary test the EBSP model was shown to be fairly successful.

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