Structural health monitoring based on aggregation-induced emission active mechanoluminescence organic material

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ABSTRACT

The current research aims to design a stress sensor using a recently synthesized organic molecule that exhibits a mechanoluminescence (ML) property. The experimental set-up is established by analyzing different application techniques and modes of capturing real-time emission along with compound and structural material interaction with other molecules. From the implemented experimentations, it was assessed that the emission color and intensity changed when applying axial pressure (direct) and showed the reversible property. This unique attribute contributed by the organic molecule shows the opportunity to develop real-time sensing and non-destructive evaluation methods of structural health monitoring.

Keywords: Structural engineering, structural health monitoring and rehabilitation, luminescence, digital image correlation.

1. Introduction

The monitoring of reinforced concrete (RC) structures through measuring local strains is a valuable procedure but only a limited number of alternative technologies are currently available, mainly including electric strain gauges and fiber optic sensors. The use of strain gauges is very common and accessible for many applications, requiring simple wiring. Another contact method is to use Fiber Bragg Grating (FBG) sensors, which shift the wavelength of reflected light as the fibers are strained. Non-contact techniques for measuring stress distribution are also available. Digital image correlation is a popular one, but it requires relatively expensive setups. The difficulty of their installation, the high cost of their sensing and/or interrogating equipment and their uncertain long-term reliability push for alternative low-cost and distributed systems, easier to install and use. PZT sensing is cost-effective and may sense change in pressure but crack is developed in the structure or not at that pressure is difficult to conclude using the PZT system [1].

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Cavity development in steel bars to install MEMS sensors is a cumbersome task and reliability of MEMS sensors is still a challenge. An organic compound has been synthesized which results in ML property on applying head-on pressure. Originally, the compound emits weak blueish green light (λem, 445nm) under excitation (λex) at 370nm. When the same compound is pressed under a hydraulic pressure, it emits strong green emission with λem, 520nm. The green emission gradually reverses into its' original form. This change of emission intensity shows a proportional relationship with the applied load [1]. This property of the compound inspires to study the response of change of luminescence intensity under bending, compression and tensile stress. The emission intensity enhancement was clearly visible at the time of crack appearance on the structural materials. This particular feature of the compound makes it promising to be applied in structural health monitoring [3].

ML phosphors can be used for stress visualization based on the linear relationship between stress and luminescence. Feng and Smet [2] mentioned that many research papers have been published in last ten years where many inorganic phosphors can be readily prepared by doping transparent crystals with luminescent ions. These types of materials in general are synthesized through solid state reactions which lead to the inhomogeneity in the product, and certainly have the impact in the luminescence property. Moreover, these materials are insoluble in solvents so its property is limited in deposition of these materials on the surface of the structural components by cheaper spin-coating/drop casting techniques. Based on this aspect, this study aims to develop a device using organic based ML to monitor the overall health of any structure. Further, the research work also monitor the dynamic loading, which generates stress over the various structural components made in building, bridges, walls etc., for the assessment of the components' integrity.

2. Experimental paradigm

2.1. Materials

A two-step process is followed to synthesis the compound. First trityl chloride (100 mg, 0.359 mmol), Et3N (50 µL, 0.359 mmol), and ethylenediamine (27.0 µL,0.359 mmol) were dissolved in THF and stirred overnight at room temperature. After the solvent was evaporated under reduced pressure, the crude product(N1-tritylethane-1,2- diamine) was collected. Later, salicylaldehyde (0.82mmol, 0.1g), N1-tritylethane-1,2- diamine (0.82mmol, 0.247g) and catalytic amount of acetic acid were dissolved in methanol and stirred at room temperature for 30 minutes. Precipitate was separated out, filtered and dried under vacuum oven for 15 min.

The crude product was recrystallized by methanol which produced a solid product. Further, M-30 grade of concrete is prepared, for the analysis of ML.

2.2. Testing

A standard cube of 15 cm x15cmx15cm of M-30 grade is taken. The compound is mixed with Epoxy and Hardener and is applied on the face of the cube. The cube is left to dry at normal room conditions for 72 hours. The baseline emission under UV is in blue region because of contribution of hardener. For flexure testing, a mild steel strip of dimension 20cmx2.54cmx0.6cm was considered. Grooves of 1 mm depth were carved at a distance of 5 cm from each end to avoid slipping during bending. A coating of chemical was done on the surface of the strip through the following steps. Strip was thoroughly cleaned with a cotton swap dipped in methanol to remove any surface dirt. A blow dryer was used to dry and heat the surface. The compound was mixed with DCM at concentration of 10-2 M and was applied on a part of the surface of the metal strip with the help of pipette and blow dried. As DCM has low boiling point, it causes the compound to recrystallize on the surface. The presence of compound was confirmed by checking for its visibility under UV emission.

3. Results and discussion

3.1. Compression testing

The compound was properly tested under compression (**Figure 1**). The compound was successfully applied on concrete as well as steel with the use of optical adhesive.

3.2. Flexure testing

Compound was dissolved in DCM (dichloro methane) and solution was poured on the strip. Strip was subjected to flexural bending test as shown. Real time video was recorded to observe the change in emission. Form the experimentation conducted, it was concluded that, it is possible to do the real time analysis. Glass fibre is absorbing the compound and showing emission and change in emission is clearly visible and image analysis can be done by taking the frames (**Figure 2**).

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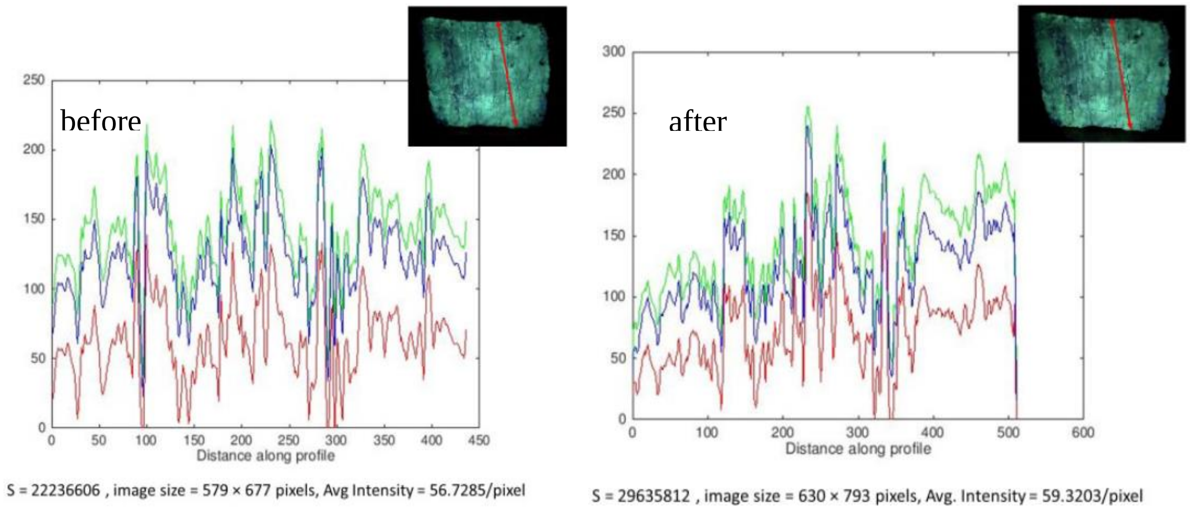

Figure 1. Interaction of compound pre- and post- compressive test.

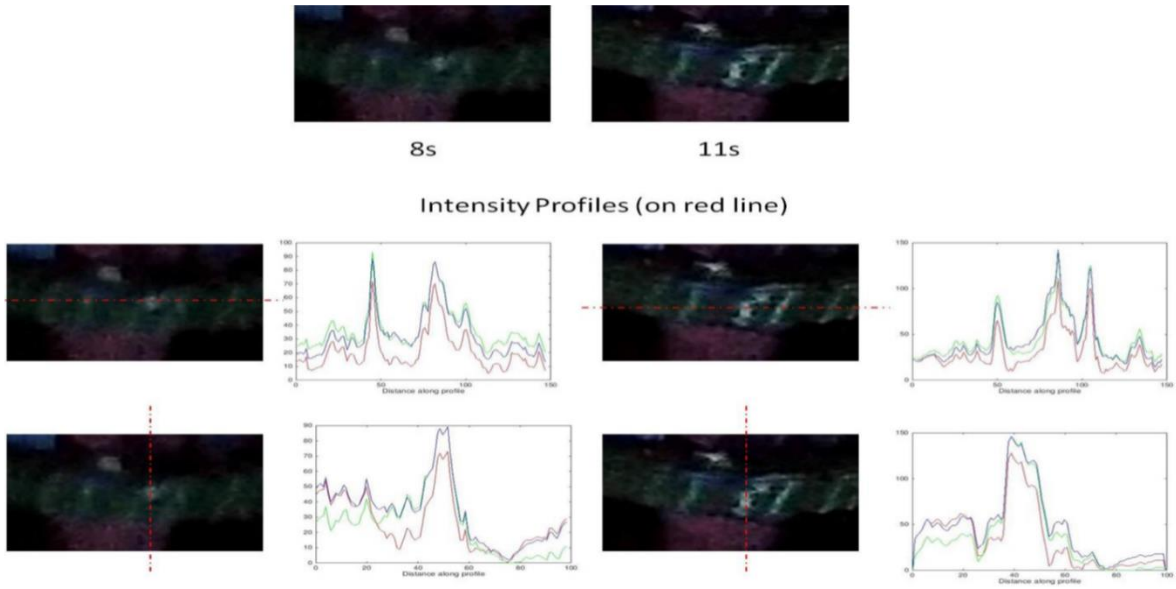

Figure 2. Image analysis of synthesized compound with the metal strip.

4. Conclusion

This research has successfully demonstrated the potential of a newly synthesized mechanoluminescent organic material as an innovative sensor for structural health monitoring. The key findings indicate that the material exhibits a reversible change in luminescence intensity and color upon the application of axial pressure, which correlates directly with the applied load. This singular property goes not only as an affirmation towards using the compound organically as sensing material and the advantages towards utilizing it since other methods involve either electric or optic strain gauges, quite often expensive as well as physically unmanageable in terms of applications [1-3]. The implications of this study are broad in the context of structural engineering, especially concerning non-destructive evaluation methods. Since this organic material was successfully used in the monitoring system, it would be more efficient, economical, and reliable. Stress concentrations and crack developments in structural components can be visualized via luminescence; therefore, the safety of structures can be improved, and interventions can be made before these failures happen, hence extending the life of the infrastructure [1]. However, some limitations were noticed during the study, including the need for further validation in a wider range of environmental conditions and loading scenarios to ensure robustness and reliability. Future research could explore the integration of this mechanoluminescent material within composite structures and its long-term performance under varying conditions. Advances in the synthetic process may further lead to improvements in luminescent properties. Such an advance would make this material more efficient and applicable across various engineering contexts. By exploring these avenues, we can fully exploit the innovative features of this research to contribute to the evolving concepts of structural health monitoring.

Conflict-of-interest statement

All the authors declare no disputes of interest, and we have no conflicts of interest to disclose.

References

[1] D. D. L. Chung, "Functional properties of cement-matrix," *Compos. Mater. Res. Lab.*, vol. 36, pp. 1315–1324, 2001.

[2] A. Feng and P. F. Smet, "A review of mechanoluminescence in inorganic solids: Compounds, mechanisms, models and applications," *Materials (Basel).*, vol. 11, no. 4, 2018, doi: 10.3390/ma11040484.

[3] M. Kinami, B. R. Crenshaw, and C. Weder, "Polyesters with built-in threshold temperature and deformation sensors," *Chem. Mater.*, vol. 18, no. 4, pp. 946–955, 2006, doi: 10.1021/cm052186c.