Paper No.
PP13

CORCON 17-20 September Mumbai, India 2017

REAL-TIME DAMAGE ASSESSMENT OF STRUCTURES USING CUSTOMISED SMART CAMERA COUPLED WITH TRIBOLUMINESCENCE SENSOR MATRIX

N.Kalaiselvi
Battery Division, CSIR-Central Electrochemical Research Institute, Karaikudi-630003, TamilNadu., kalakanth2@yahoo.com

R.Vedalakshmi, SP.Manoharan, R.Monika
Corrosion and Materials Protection Division, CSIR-Central Electrochemical Research Institute, Karaikudi-630 003, Tamilnadu.,

ABSTRACT

A nation's prosperity is measured by the type of the infrastructures it possesses. Consequently, the society faces major challenges with the deteriorating health of civil infrastructures that includes roads, bridges, dams and nuclear installations. Excessive loads, accidents and/or environmental degradation could cause various types of damage. Today, damage detection techniques are carried out at regular intervals by visual inspection manually. If left undetected, the accumulated damage could diminish the structural performance, serviceability and safety. Timely detection of damage is crucial for facilitating necessary structural repairs, ensuring optimal performance of structures and enhancing public safety. In this direction a new inspection paint' by incorporating high triboluminescence (TL) intensity phosphor into a acrylic resin to detect failures related to structural components has been developed.

This paint shall apply on the structural components (either steel or concrete) to be examined and act as a sensor matrix. When the fracture/crack occurs in structure, it will lead to the fracture of the TL crystals which are present on the surface of the structure results a light emission. The signal originating from the TL paint as a transient event will be captured by a specially designed and

properly tuned dedicated camera, appropriately customised for background correction and fitted at the right place. After image processing the signal received, the location of crack/failure, crack width and crack length will be determined. This technique is more appropriate to identify failure of cables in cable stay bridges which may occur at inaccessible locations.

Using solvent evaporation method, various organic/inorganic crystals were synthesised and their intensity was determined using standard drop tower test. Using flourolog-3 spectrometer the TL intensity was determined. After application of TL paint on cylindrical concrete specimens, the TL intensity was tested under compression and impact load using force gauge test. TL signal emitted from the sensor matrix was captured by camera and was image processed using Matlab to know the crack width and length. From the laboratory investigations it can be concluded that smart camera coupled with the TL sensor matrix able to assess the damage in large scale field structures with in-built remote monitoring.

Keywords: Triboluminescence, phosphor, remote monitoring

INTRODUCTION

Society faces major challenges with the deteriorating health of civil infra structures.Today crack detection techniques are carried out at regular intervals by visual inspection and ground penetrating radar as per national guidelines. But using these methods are still limited as a comprehensive crack sensor since cracks can go unnoticed where variable load conditions occur frequently. Other non-destructive inspection protocols such as ultrasonic pulse velocity technique and dye penetrants are used for damage detection. Further, Ground penetrating radar (GPR) is often used to evaluate the presence of cracks or imperfections in bridge decks, foundations and pipelines. Similarly, Fiber bragg grating engraved on optical fibers that are embedded into concrete structures can perform as strain gauges and can foretell catastrophic failures. Electrical impedance tomography (EIT) is being used to detect cracking of cementitious materials under tension. It is also reported that RFID tag antennaa based sensing has also been attempted at laboratory level to detect cracks. The greatest limitations of all these techniques are location based and not able to detect if the failure occurs at other places. However, real-time remote monitoring of structure is not possible.

In recent years, TL materials have been proposed as smart material to sense damage of various structural components such as building, bridges, aircraft, spacecraft and so on. (1-7). Recently to visualize in situ crack propagation of structural components using TL has been explored in order to analyse the stress field around the crack tip. These materials are embedded into a suitable composite/binder and fixed/applied on the structural components to be examined. When the damage/fracture occurs in structure, it will lead to the fracture of the TL crystals resulting a light emission,thus converts mechanical energy into light energy. It is reported that organic/inorganic crystals having non-centrosymmetric / centrosymmetric structure with piezoelectric property exhibit triboluminescence (8,9). Ishihara et al (10) reported that hexacelsian doped with rare earth elements such as Eu,Sm,Yb and Ce exhibits intense luminescence upon cleavage Park et al., (11) reported that 1,2-bis(4-(4-*tert*-butylphonoxy) phenyl)ethane-1,2-dione (BBPE) and substituted benzil derivative of it emit an intense green light upon scratching. Fontenot et al.,(12-14) compared the triboluminescent properties of dibenzoylmethide triethyl ammonium (EuD_4TEA) with that of ZnS:Mn and inferred that EuD_4TEA produced 106% higher TL intensity than ZnS:Mn and it depends on crystal size. Eliseeva et al.,(15) found that crystalline polymers assembled from lanthanide β-diketonates and aromatic bidentate *O*-donor ligands exhibit strong triboluminescence, which could be useful in the design of pressure and/or damage detection probes.

EXPERIMENTAL PROCEDURE

Preparation of TL Compound

The phosphor namely europium dibenzoylmethide triethyl ammonium (EuD_4TEA) was prepared by dissolving 4 mmol of europium (III) nitrate hydrate in 40 ml of acetone.The solution was stirred without heating for 15 minutes using magnetic stirrer .Then 13 mmol of dibenzoylmethane was added and stirring was continued for 1 hr. To this solution,14 mmol of triethylamine was added and stirred at 40^0 C for 1 hr. The solution was left for 48 hrs at room temperature, to allow crystals be formed and precipitated. Finally, pale yellow colour crystals were formed and collected using a vacuum filtration then dried in a desiccator for 2 hr. The size of the crystals were found to be varied from 1 to 10 mm and were reduced to 150 -300 micron by manual grinding so as to enable to incorporate into the acrylic resin matrix. Resin was prepared by dissolving 20 gm of acrylic powder in 80 ml of xylene. The mixture was kept overnight and clear resin was obtained. The TL paint was prepared by intergrinding 25 ml of resin and 12.5 gm of TL crystal in a ceramic mortar. The solid content of the resin was varied from 20-40 %.

Casting of Concrete Specimen

Concrete specimens of size 50 mm dia x 50 mm height were cast using the mix proportion of 1:2:4 After curing for 3 days, the specimens were dried at 100^0 C for 3 hr in oven to remove the surface moisture. Prepared TL paint was applied on the dried concrete surface by brush and allowed to dry in air for 48 hr at room temperature.

Standard Drop Tower Test

Once the crystals were completely dried, the triboluminescent yield of EuD_4TEA was measured using a custom- built drop tower as shown in Fig.1. About 0.1 g of phosphor crystal was kept inside the specimen holder and was positioned around the center of the drop tube through which ball will be dropped at known height. A known weight of steel ball (110 g) was positioned on a pull pin which is kept at a known distance above the material. The distance varied from 35, 65, 95 and 110 cm to produce an impact energy of 385,715,1045 and 1210 mJ on the sample respectively. The pin was pulled, and the ball fell and impacted phosphor crystal thus producing TL emission, which was captured by an external optical cable connected to a flourolog-3 spectrometer to get a TL spectrum in the time domain. From the TL spectrum , intensity was determined and the results are given in Fig.2.

Force Gauge Test

Compressive load was applied using force gauge as shown in Fig 3. When crack appeared on the coated concrete surface, TL paint emit signal, which was captured by an external optical cable connected to a flourolog-3 spectrometer to get a TL spectrum in the time domain and TL intensity was determined. The results are given in Fig.4. Similarly TL paint was applied on steel specimen and pulled using force gauge. TL intensity of emitted signal upon fracture was recorded and given in Fig.5.

RESULTS

Effect of grain size on TL intensity

Fig 2(a) & (b) compares the TL emission of EuD_4TEA phosphor at 150 µm and 300 µm size respectively. Plots are showing the intensity is depending upon the impact energy and size of the crystal. The highest intensity of 25000 cps was obtained when the steel ball hit on 300 µm crystal size at the impact energy of 1215 mJ (110 cm height of fall) whereas lowest intensity of 5000 cps was obtained at the impact energy of 385 mJ on 150 µm crystal size. Maximum intensity of 40000 cps was obtained on 300 µm size crystal at the impact energy of 1045 mJ. Studies concluded that 300 µm size crystal shall be incorporated into a resin when preparing the TL paint.

Effect of TL intensity on concrete surface under impact load

From Fig.4, the highest TL intensity of 20000 cps was emitted at the impact energy of 385 mJ on TL coated concrete surface. It is also inferred that the intensity is independent of impact energy but dependent on % of solid content of acrylic resin.. Phosphor incorporated into a 20 % acrylic resin emit highest intensity in the range of 10,000-20,000 cps whereas it is lowered to 5000-10,000 cps when the sold content increased to 30-40 % . From the studies it can be concluded that 20 % solid content is an optimum level to get maximum TL intensity. In contrary to this, when the size of the crystal in 20 % solid content of acrylic resin is increased to 300 µm, the maximum TL intensity of 17000 cps was obtained at the impact energy of 1215 mJ which is lowered to 15000 cps at 30 % solid content of acrylic resin. The intensity is less than 10000 cps when the impact energy is equal to or less than 1045 mJ.

TL emission on coated concrete under compressive/tensile load

The signal emitted by the TL sensor matrix on concrete surface under compression load was captured by customized camera and given in Fig.5. From this signal, the intensity was arrived using the MATLAB software. Crack width arrived was 1.17mm. Fig .6 shows when TL coated steel specimen failed under tensile load.

CONCLUSIONS

1. Highest TL intensity was observed under tension load than at compression and impact load.
2. TL intensity strongly depends upon the magnitude of the stress rather than the type of the load.
3. Customised smart camera able to capture the signal emitted by TL sensor matrix when crack/failures occurred in structural components.
4. Real-time failure monitoring of structure is made possible using the developed customised smart camera.

REFERENCES

1. C. J. Lee, et al., Visualization of Quasi-static Crack Propagation in Splitting Test of Concrete by Using Mechano-luminescence*,* 9th International Conference on Fracture & Strength of Solids. **2013**, June 9-13.
2. Sage, I, L Humberstone, I. Oswald, P. Lloyd and G. Bourhill, Getting light through black composites: embedded triboluminescent structural damage sensors. *Smart Materials & Structures,***2001,** 10(2), 332-337.
3. W. A. Hollerman, S. M. Goedeke, N. P. Bergeron, C. I. Muntele, S. W. Allison, D. Ila, Effects of Proton Irradiation on TL Materials Such as ZnS:Mn,*Nuclear Instruments and Methods in Physics Research,***2005**, 241B, pp. 578–582,
4. B. P. Chandra, C.N. Xu, H. Yamada, X.G. Zheng, Luminescence induced by elastic deformation of ZnS:Mnnanoparticles. *Journal of Luminescence*, **2010.** 130(3), 442-450.
5. I. Sage, R. Badcock, L. Humberstone, N. Geddes, M. Kemp and G. Bourhill, Triboluminescent Damage Sensors, *Smart Materials and Structures*, **1999**,Vol. 8, 504–510.
6. NaoTerasaki and Chao-Nan Xu, Historical-Log Recording System for Crack Opening and Growth Based on Mechanoluminescent Flexible Sensor, *Ieee Sensors Journal*, **2013**, 3, 10.
7. Duell, J.M., Impact Testing of Advanced Composites, in:Advanced Topics inCharacterization of Composites, M.R. Kessler, (Edi). **2004**, Trafford Publishing:Victoria, BC, CANADA.
8. Bukvetskii, B.V., et al., Crystal Structure And TriboluminescenceOf The [Eu(Tta)2(No3)(Tppo)2] Complex,*Journal of Structural Chemistry*,**2006** , 47(3), 575-580.
9. B. V. Bukvetskii, et al., Crystal Structure And TriboluminescenceOf Centrosymmetric Complex $[Eu(NO_3)_3(Hmpa)_3]$, *Journal of Structural Chemistry*. **2010**, 51(6) 1164-1169.
10. T.Ishihara, K.Tanaka, K.Fujita, K.Hiraob and N. Soga Full color triboluminescence of rare-earth-doped hexacelsian ($BaAl_2Si_2O_8$)Solid State Communications. 107, (12), 763-767, 1998
11. H.Young Park, J.Lee, K. Parkand J.M Kim A New Triboluminescent Material *Bull. Korean Chem. Soc.* 2011, Vol. 32, No. 2 401-402
12. R.S Fontenot, W. A Hollerman, K.N Bhat and M.D Aggarwal Comparison of triboluminescent properties of europium tetrakis and ZnS:Mn powders. Journal of Theoretical and Applied Physics 2012, 1-9.
13. R.S Fontenot, W. A Hollerman, K.N Bhat and M.D Aggarwal, Triboluminescent materials for smart sensors,Materials Today,14,6(2011), 292-293.
14. R.S Fontenot, W. A Hollerman, K.N Bhat and M.D Aggarwal, effects of crystallite grain size on the triboluminescent emission for EuD_4TEA. Advanced Materials and Letters.2013, **4**(8), 605-609.
15. S.V. Eliseeva, D.N. Pleshkov K.A. Lyssenko, L.S. Lepnev, J. G. Bünzli, and N.P. Kuzmina.,Highly Luminescent and Triboluminescent Coordination Polymers Assembled from Lanthanide β-Diketonates and Aromatic Bidentate*O*-Donor Ligands,*Inorganic. Chemistry*, **2010**, *49* (20), 9300–9311

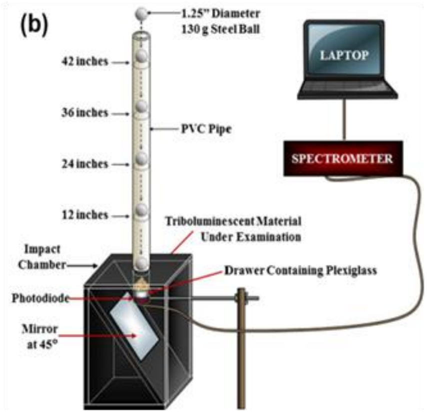
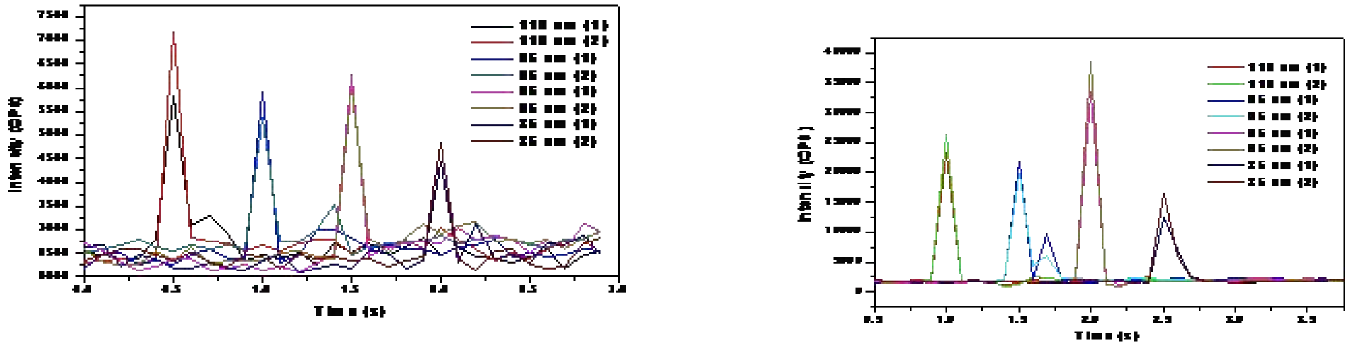


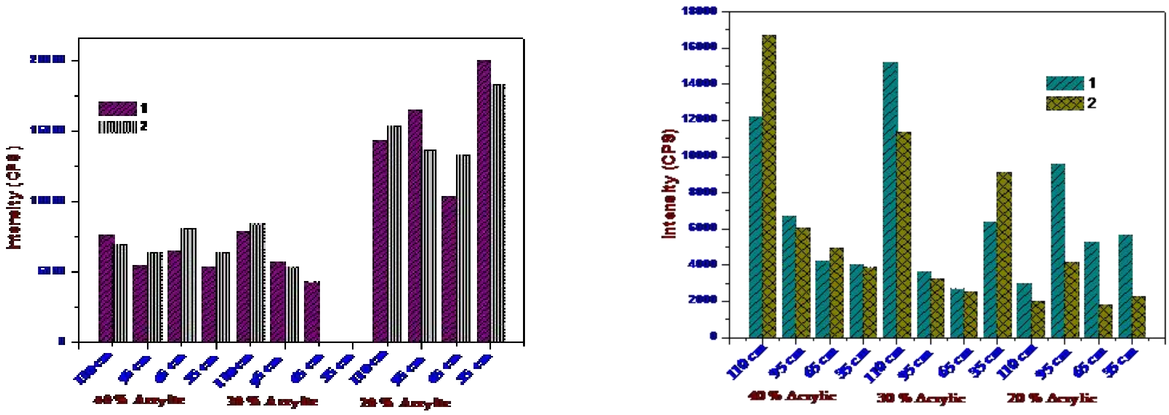
Fig.1: Standard drop tower test



(a) (b)

Fig.2 : Comparison of TL emission of phosphor under impact load: (a) 150 µm size (b) 300 µm size

Fig.3: Test set up to measure TL intensity of phosphor under compressive/ tensile load



(a) (b)

Fig.4 : Comparison of TL intensity on coated concrete under impact load (a) 150 µm (b) 300 µm

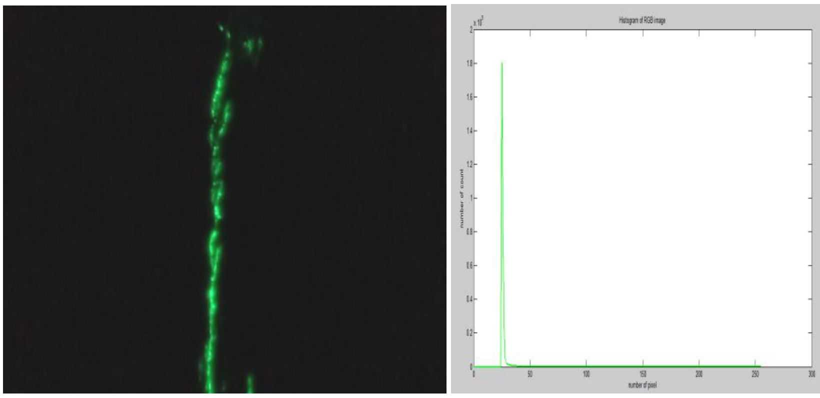


Fig.5 : Signal emitted and its intensity when concrete cracked under compressive load

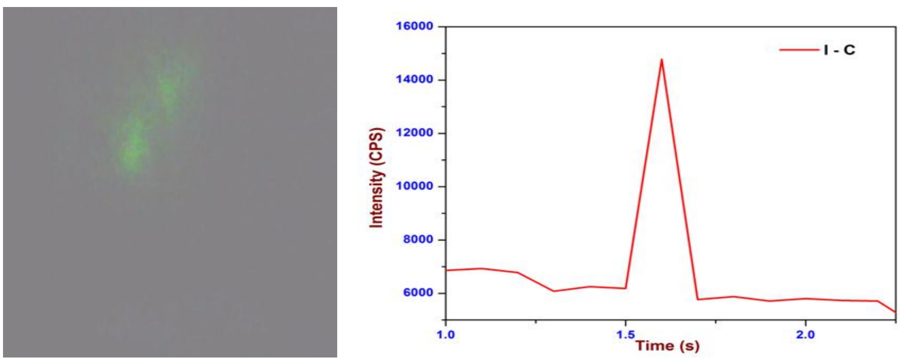


Fig.6: TL intensity under tensile load