MECHANOLUMINESCENCE: A NOVEL METHOD FOR IDENTIFICATION OF CRACK INITIATION IN CONCRETE STRUCTURES

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ABSTRACT. The paper reports phenomenon of mechanoluminescence (ML) in concrete crystal which is synthesized by conventional method. The mechanoluminescence induced by impulsive excitation of concrete crystal plays a significance role in the understanding of cracks formation and it is applicable as crack sensor, fracture sensor or damage sensor. It is also applicable for ML induced by deformation of crystal in certain ways. It is useful for civil engineering application with different impulsive velocity.

Keywords: Mechanoluminescence, Concrete crystal, X-Ray diffraction, Crack identification

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INTRODUCTION

It is well known from the studies that cracking of the hardened concrete is mostly due to three mechanisms namely, drying shrinkage, autogenous shrinkage and thermal stresses. Loss of moisture from the cement or concrete mixes, results in volume change and finally restrained drying shrinkage occurs. The volume change and restraint creates tensile stresses in the concrete followed by cracking. These tensile stresses are affected by amount and rate of shrinkage, rate of shrinkage, modulus of elasticity and creep. Type of cement and aggregate plays a vital role for amount of drying shrinkage.

The transverse cracking and deterioration of concrete bridge decks is the major area where normal damage resulting due to mechanical action or impact. The causes of early age cracking are primarily attributed to plastic shrinkage, temperature effects, autogenous shrinkage, and drying shrinkage. They performed experimental and field testing to investigate the early age transverse cracking of bridge decks and evaluate the use of sealant materials [1].

Luminescence is spontaneous emission of light by a substance not resulting from heat; it is thus a form of cold-body radiation. It can be caused by chemical reactions, electrical energy, subatomic motions or stress on a crystal (Wikipedia). Luminiscence induced due to any of the mechanical process like grinding, rubbing, cutting, cleaving, shaking, scratching, compressing or by impulsive crushing on solid is known as mechanoluminescence (ML). ML can also be excited by thermal shocks caused by drastic cooling or heating of materials or by the shock waves produced during exposure of samples to powerful laser pulses. ML phenomenon is produced under different mechanical actions are sometime given specific names, such as triboluminescence, piezoluminescence, elastico and fracto luminescence, respectively. Mechanoluminescence is used to describe the whole variety of processes in which light is emitted due to application of mechanical energy on solids. At present this effect is used widely in investigation of deformation and fracture of solids. This technique offers a number of interesting possibilities such as detection of cracks in solids and for mechanical activation of various traps present in the solids.

Strontium is the chemical element with symbol Sr and atomic number 38. An alkaline earth metal, strontium is a soft silver-white yellowish metallic element that is highly chemically reactive gives luminescent properties which can be seen and recorded only with special equipment. Rare earth(terbium(Tb), dysperium(Dy) and europium(Eu) doping may be done to observe ML patterns on crack developed due to any of the external reasons, like, dynamic responses through vibrations, impacts, continuous vehicle movement over bridges, bomb explosions earthquake, and Volcano eruptions. The rare earth generally doped in suitable concentration with calcium (Ca), silica (Si), aluminium (Al) and magnicium (Mg) present as oxide forms in cement gives luminescent to show even micro cracks and suitable corrective meausers may be taken to avoid major damage and cost involved[2-8]

Stress behavior of structural component may be observed by non-contact method to visualize stress distributions based on mechanoluminescence (ML). This method is novel than earlier used strain gauges, optical fiber sensors, X-Ray diffraction and digital image correlation. They used $(Ca_{0.4}Sr_{0.6}) Al_2Si_2O_8:1\%Eu^{2+},1\%Ho^{3+}$, a glow-in-the-dark material [9].

Soy-based luminescent sealant have been used on concrete surfaces. The luminescent sealant is a mixture of soy methyl ester polystyrene (SME- PS) and strontium aluminate; a phosphorescent powder that slowly luminesces after being excited by light [10].

The special phosphorescent cement is manufactured just like regular cement, though the researchers noted that the addition of phosphorescent materials does change the structure of the finished product. As a result, this glowing cement would likely only be used as a coating material on top of other surfaces such as standard cement [11]

Light emmiting concrete have also been developed with the approach of remote highways for clear identification of road boundaries. The light emitting concrete composition comprises light-emitting pigments. The light emitting pigments include a titanium powder, a sulphide powder and resins, cement, sand, gravel and water [12].

In our study, when phosphor is impulsively deformed, fracture occurs in phosphor. It is called fracto ML (FML). In the FML induced by impulsive deformation, a moving piston makes an impact on to a crystal and the ML is produced during fracture of the crystal.

MATERIAL CHARACTERIZATION

2.1 Cement Portland-Pozzolana Cement confirming to IS 1489 (Part 1): 1991 was used as binding material.

2.2 Fine Aggregate Locally available river sand of specific gravity 2.64, water absorption 0.8% and fineness modulus of 2.62 was used as fine aggregate in the concrete mix.

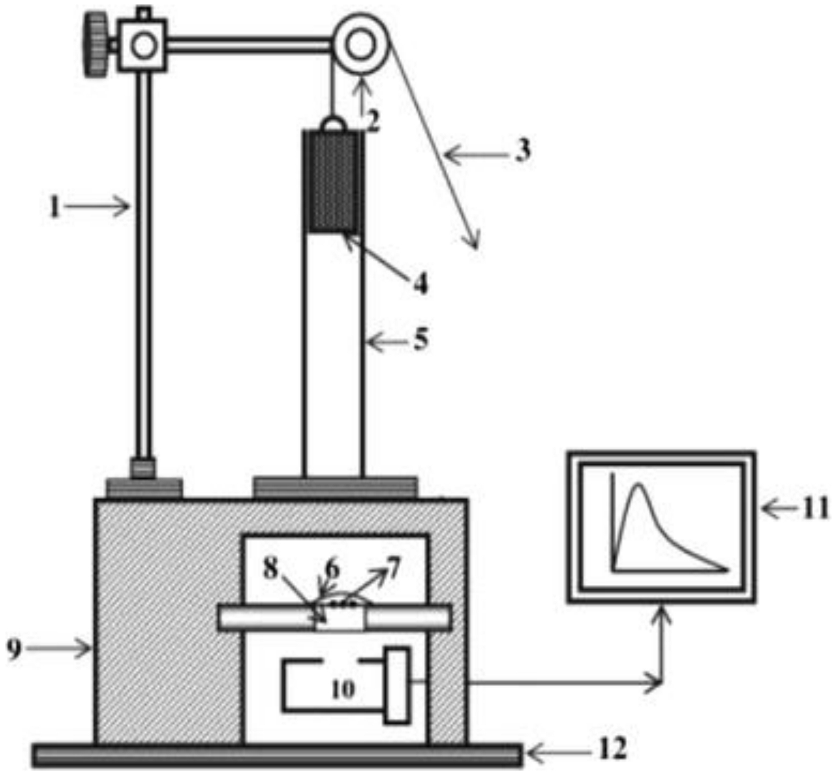
2.3 Coarse Aggregate Crushed lime stone of 20mm and down-graded was used as coarse aggregate of specific gravity 2.67, water absorption 0.6% and fineness modulus of 6.2.

CONCRETE MIX PREPARATION

The design mix Concrete of grade M 20 with target mean cube compressive strength of --- 27.59 N/mm^2 after 28 days of curing have been used for preparation of specimen. This has been achieved by mixing all the calculated constituents of concrete i.e. cement, fine aggregates and coarse aggregates in proportion of 1:1.63:2.54 (cement: sand: coarse aggregate) by weight in dry condition in pan mixer of laboratory. The water cement ratio was added to make a uniform mixture in wet condition. This mixture was used to make required no of samples with cube mould of 150mm x 150mm x 150mm and compressive strength were recorded after various exposer periods. ML pattern have been taken for the samples collected from cubes surface up to 5 mm depth [13-15].

4.0 EXPERIMENTAL PROGRAMME

The experimental setup used for impulsive excitation of ML in -ray irradiated through concrete samples which was collected after 28 days of submerged water curing is as follows, sample was placed on the upper surface of a transparent Lucite plate. This was covered with a thin aluminum foil and fixed with adhesive tape. For determining the peak intensity, peak position, rise and decay time of ML, trace on the oscilloscope screen was recorded on tracing paper. Fig (1) shows the schematic diagram of experimental set-up used for deforming the sample and measuring the ML. When the 450 gms load was dropped from 55 cm height on sample, there was impulsive deformation of crystal occurs. Mechanoluminescent intensity is sensed by photomultiplier tube and ML pattern traced by storage oscilloscope,which is connected by photomultiplier tube.



1.Stand
2. Pulley
3.Metallic wire
4. Load
5.Guiding Cylinder
6. Aluminum foil
7. Sample
8. Transparent Lattice plate
9. Wooden block
10. Photomultiplier tube
11. Digital storage oscilloscope
12. Iron base mounted on table

Figure 1 Experimental arrangements of ML measuring device

RESULTS AND DISCUSSION

Mechanoluminescence characteristics of concrete crystal induced by the impact of a moving piston of weight 500 g onto the crystal were measured (Figure 2). In ML intensity versus time curve single peak is observed. The presence of a single peak indicates some charge transfer process involved in ML emission. The luminescence intensity depends upon impact velocity. The experiment was carried out for different impact velocities i.e. same weight dropped with different heights. ML emission is mostly due to the deformation of sample. In present study when crystal is mechanically deformed, the electric field introduced during the deformation either ionizes the electrons from the defect center or from the valence band, electron thus obtained in conduction band may either recombine directly with the holes present in the luminescence center or recombination center, or they may be trapped for some time in the trapping levels present near the conduction band.

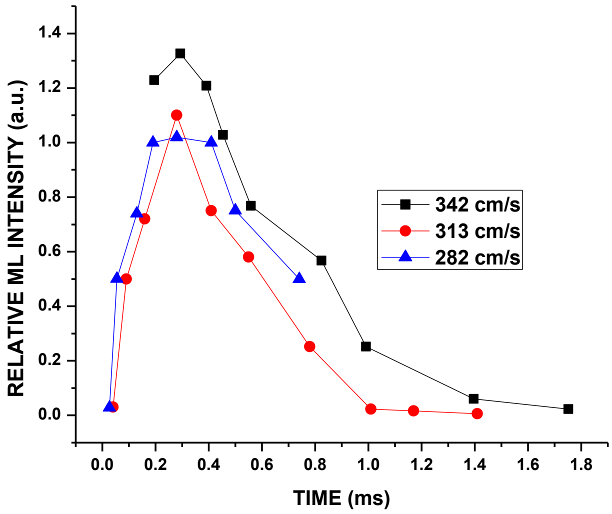


Figure 2 ML pattern of concrete crystal with different impact velocity

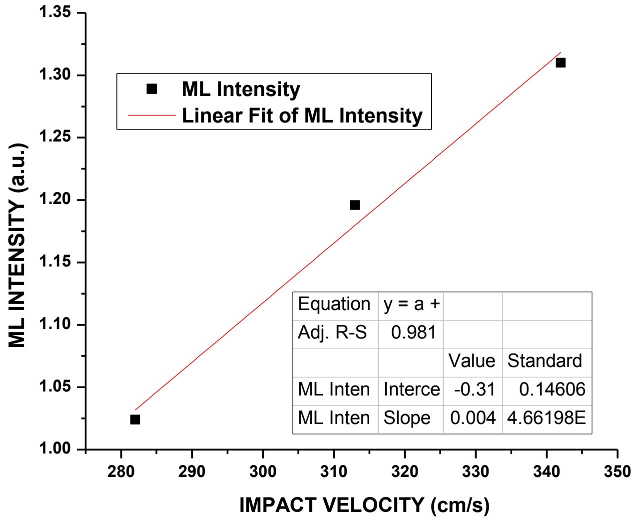


Figure 3 Impact velocities versus intensity plot

It is shown in fig 2 that initially ML intensity is increases with impact velocity then attains a maximum value, then decreases with further increases in impact velocity. In fig 3 peak ML intensity is increases linearly for different impact velocity. Since the R-square value is found to be 0.981, indicates the best fitment and conformity of the results.

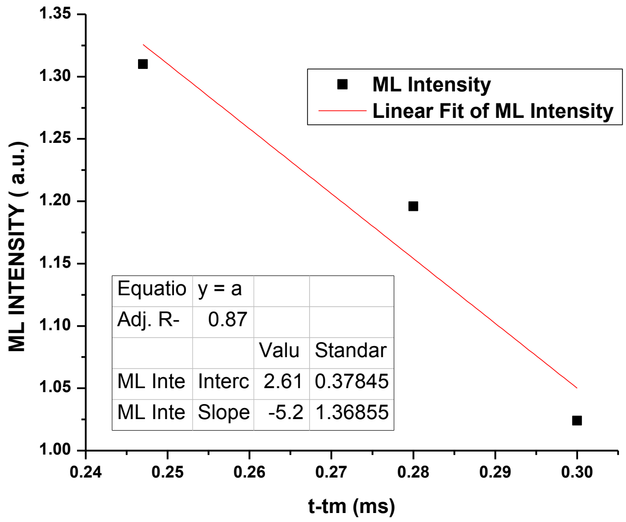


Figure 4 (t-t_m) versus ML intensity

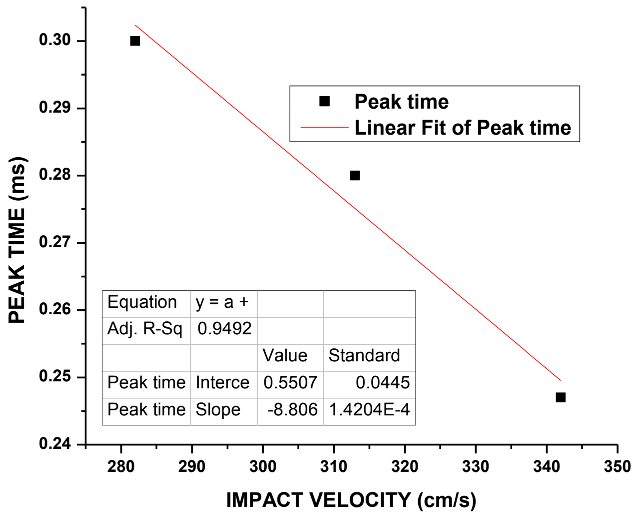


Figure 5 ML peak time(t_m) versus impact velocity

Figure 4 shows that ML intensity decreases linearly with t-t_m. In Figure 5, it is shown that peak time t_m decreases with increasing impact velocity because deformation occurs earlier at higher impact velocity

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Theory of Mechanoluminescence induced by impulsive deformation

As we know that mechanoluminescence is a type of luminescence in which solid samples are mechanically deformed. Generally some materials known as phosphors mixed in variable concentrations which give luminescence on external action (mechanical action like impact in our case). In our study, when concrete crystals were impulsively deformed, fracture occurs. It is called fracto ML (FML). In the FML induced by impulsive deformation, a moving piston makes an impact on to a crystal and the ML is produced during fracture of the crystal. Let dN be the number of cracks produced during the change of strain from e to (e+de), then dN may be written as

$$dN = M\,de \tag{1}$$

where, M is the correlation factor between the number of cracks and the strain of the crystals [2].

X-RAY DIFFRACTION ANALYSIS

X-ray diffraction analysis as shown in Fig 7 have been made to confirm calcium carbonate present at 2 theta, 29.54° (intense peak) and Crystal structure Orthorhombic structure and crystalline size in nearly 80 nm ranges confirming to ICDD standards. This confirms that doping of rare earth in designed concentration gives ML response. The formula used is as;

$$D = \frac{n\lambda}{2d\sin\theta}$$

Where, D= Crystallite size, n = no. of intervals, d= inter-planner distance, θ = diffraction angle, λ = wavelength of X-ray

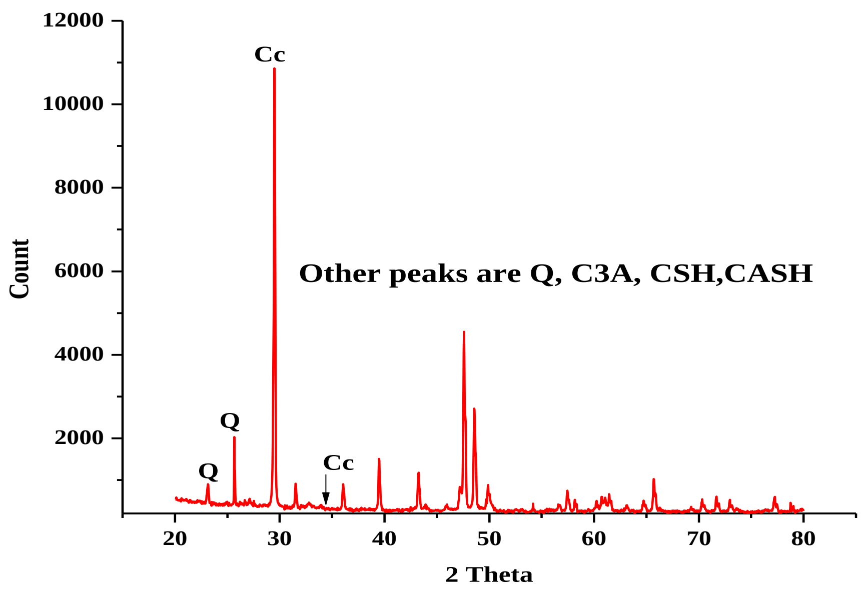

Figure 7 XRD spectrums of concrete OPC SA after 28 days of curing (Q = Quartz / Silicon Oxide; CASH = Calcium alumino silicate hydrate; CSH = Calcium silicate hydrate; C_3A = Orthorhombic aluminate).

CONCLUSION

From the present study, we have concluded that when concrete crystal is deformed impulsively, deformation occurs. Single peak is observed in ML pattern of concrete crystal.ML intensity increases with impact velocity attain a maximum value then decreases with the further increase of impact velocity. peak time tm decreases with increasing impact velocity because deformation occurs earlier with increasing impact velocity . ML intensity increases linearly with the mass of crystals.ML study of concrete crystal may be helpful for the study of crack propagation of in the crystals and provide important information about mine failure and earthquake determination. We may repeat the same process using rare earth to get cold body emission and clarity in visible light after any mechanical damage of concrete. This may be utilized to safeguards against any possible damage of property and life of human beings.

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