Journal of Luminescence 131 (2011) 1407–1418

Contents lists available at ScienceDirect

Journal of Luminescence

journal homepage: www.elsevier.com/locate/jlumin

Review

Progress in triboluminescence-based smart optical sensor system

David O. Olawale [a], Tarik Dickens [a], William G. Sullivan [a], Okenwa I. Okoli [a,*], John O. Sobanjo [b], Ben Wang [a]

[a] High-Performance Materials Institute, FAMU – FSU College of Engineering, 2525 Pottsdamer Street, Tallahassee, FL 32310, USA
[b] Department of Civil and Environmental Engineering, FAMU – FSU College of Engineering, 2525 Pottsdamer Street, Tallahassee, FL 32310, USA

ARTICLE INFO

Article history:
Received 15 November 2010
Received in revised form
8 February 2011
Accepted 8 March 2011
Available online 15 March 2011

Keywords:
Triboluminescence
Sensors
Structural health monitoring
Smart structures
Composites

ABSTRACT

Extensive research work has been done in recent times to apply the triboluminescence (TL) phenomenon for damage detection in engineering structures. Of particular note are the various attempts to apply it in the detection of impact damages in composites and aerospace structures. This is because TL-based sensor systems have a great potential for wireless, in-situ and distributed (WID) structural health monitoring when fully developed. This review article highlights development and the current state-of-the-art in the application of TL-based sensor systems. The underlying mechanisms believed to be responsible for triboluminescence, particularly in zinc sulfide manganese, a highly triboluminescent material, are discussed. The challenges militating against the full exploitation and field application of TL sensor systems are also identified. Finally, viable solutions and approaches to address these challenges are enumerated.

Contents

1. Introduction

The triboluminescence (TL) phenomenon has generated extensive research interest over the years because of its potential application for damage detection [1]. Triboluminescence also known as fracto- [2], piezo- [3], or mechano-luminescence [4], is the emission of light by solid materials when they are stressed or fractured [5,6]. It has been estimated that about 50% of all crystal compounds exhibit a range of TL [7].

Although TL was reportedly discovered in the sixteenth century by Sir Francis Bacon, serious research into the phenomenon only began in the twentieth century. The main contribution of early nineteenth

* Corresponding author. Tel.: +1 850 410 6352; fax: +1 850 410 6342.
E-mail address: okoli@eng.fsu.edu (O.I. Okoli).

0022-2313/$ - see front matter
doi:10.1016/j.jlumin.2011.03.015

century research was the compilation of an extensive list of TL materials using highly subjective visual observation of the TL response as a function of time and quantity [7]. However, the development of the photomultiplier tube (PMT) in the 1930s and its application in triboluminescence studies in 1952 introduced a quantitative technique for detecting, measuring, and comparing TL emissions objectively. More recently, researchers have investigated the application of TL in damage detection [1,6].

There are a number of techniques currently being used for damage detection and monitoring of civil, aerospace, and military structures. These include acoustic based methods (acoustic emission and ultrasonic testing) [8–11]; electro imaging methods such as thermography, ultrasonic pulse velocity (UPV), and ground penetrating radar (GPR) [12–23]; radiography such as X-ray, gamma-ray, and neutron ray [24]; and fiber optics methods [24–26]. The major drawbacks of these techniques are that they do not provide in-situ (excluding fiber optic methods) and distributed sensing [9,25,26]. These prevent monitoring the structural states in real-time. Furthermore, the associated cost resulting from the downtime required for periodic nondestructive inspections can be very high for aerospace structures like aircrafts and civil structures like bridges. There is also the prohibitive cost arising from fatal accidents when such structures fail without warning. Table 1 gives an overview of the strengths and limitations of some of the nondestructive evaluation methods currently in use.

Triboluminescence-based sensor systems may be able to overcome the fore mentioned challenges since they have the potential for wireless, in-situ, and distributed (WID) sensing that can enable real time continuous monitoring. A TL-based sensor system comprising highly efficient triboluminescent materials could allow simple, real-time monitoring of both the magnitude and location of damage with minimal parasitic influence to the host structure [27,28]. They can be used as stress, fracture, and damage sensors [29,30]. They have also been proposed for visualizing the stress field near the crack-tip, stress distribution in solids, and quasidynamic crack-propagation in solids [29,31–35].

Recent research in triboluminescence includes those on [1–7,27,28,32,36,37]:

(i) Techniques to initiate the triboluminescent light emission with a known amount of mechanical energy, so as to investigate the relationship between mechanical energy input and the resulting TL emission intensity [38,39].
(ii) Techniques to measure the TL emission spectrum [39,40] with increased resolution and with a reduction in both the amount of triboluminescent material required and the time needed to obtain the spectrum.
(iii) The analysis of the spectral properties of the TL so as to understand the underlying mechanism of fracture-induced light emission [41,42].

In spite of all these research efforts, there is no information contained in the open literature that suggests commercial use of TL as a damage sensing mechanism [27]. This article provides information on the current state of development of TL-based sensor systems for composite and concrete structures, with emphasis on aerospace and civil applications. Longchambon (1925) provided a detailed review on TL research up to about 1925 [7]. The review by Walton [7] covered principal work from approximately 1930 to 1975. Since then, various completed research have been focused on gaining a better understanding of the TL phenomenon and its application for damage sensing.

This article provides a review of such efforts from 1980 up to the present date. The progress that has been made in using the TL phenomenon to detect and quantify intrinsic damage due to impact events reported by workers such as Womack et al. [1], Bergeron et al. [6], and Chandra and Zink [29], will be highlighted in this work. Low, as well as high velocity impacts that are experienced in aerospace applications will be discussed. Furthermore, the challenges facing the successful development of TL-based sensor systems in advanced material applications are identified, and possible solutions proffered.

Table 1
Summary of some existing NDT techniques for engineering structures.

Techniques	Benefits	Limitations
Acoustic		
• AE	Able to monitor internal microscopic damage	Weak signal
• UT (pulse-echo and impact-echo)	Most commonly used, able to detect internal flaws and delaminations	Requires highly skilled personnel, stress waves attenuation in concrete, not distributed, time consuming, labor intensive
Electromagnetic imaging		
• Thermography	Able to locate internal cracks and defects	Limited applications for decks with asphalt overlays, high cost, disruptive to traffic, accessibility problems
• Ground penetrating radar (GPR)	Most promising imaging methods for locating internal defects in concrete, able to collect large data at high speed	Requires highly skilled personnel, involves complex analysis, expensive
Radiography		
• X-rays and gamma-rays	Able to detect defects such as porosity, voids and inclusions of appreciable thickness and parallel to radiation beam	Limited ability to detect plain defects such as cracks, crack detection dependent on crack orientation to radiation beam, health and safety concerns
• Neutron radiography	Use in studying internal crack patterns in concrete, shows more cracking than X-ray and gamma-ray	Limited application on large scale structures like bridges
Fiber optic sensors		
• Fabry–Perot	Gage lengths is similar to conventional strain gauges; high temperature, shock and vibration resistant; high precision	Requires calibration
• Fiber Bragg Grating	Multi-parameter sensing of strain, temperature, acoustic, pressure, corrosion, etc.; multiplexing capability; requires no calibration	Expensive set up and components; high temperature sensitivity
• Bending loss (intensity based)	Economical, possible coverage of wide area	Direction of crack formation needs to be known, complicated measurement due to differential shrinkage of concrete