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Fracture studies on synthetic fiber reinforced cellular concrete using acoustic emission technique

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HIGHLIGHTS

- Fracture behavior of hybrid fiber reinforced CLC is studied using acoustic emission (AE).
- Synthetic fibers improved the fracture behavior of CLC.
- Hybrid fibers showed better performance compared to only macro-structural fibers.
- Three dimensional source location of cracks is carried out based on the AE events.
- AE energy correlates with fracture energy. It increases with increase in fiber dosage.
- Crack width can be measured indirectly through the number of AE hits observed.

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ABSTRACT

Cellular lightweight concrete (CLC) is increasingly used for low strength non-structural and structural applications. The effects of synthetic fiber reinforcement on the fracture behavior of CLC is investigated. In particular, acoustic emission (AE) technique is employed to study the influence of macro (structural), micro polyolefin synthetic fibers and their combinations on the fracture behavior of CLC beams. Notched fiber reinforced CLC beams were tested to study the crack initiation and propagation characteristics using AE sensors. Different AE parameters are correlated with the crack growth and damage accumulation. An attempt has been made to correlate the crack mouth opening displacement (CMOD) with the number of AE hits. The variation of cumulative acoustic energy release of the cracks is studied with respect to applied load and CMOD. Three dimensional source location of cracks is carried out based on the AE events picked by the sensors bonded to the CLC specimens. The analysis of AE results indicates that the crack source location identification from AE is consistent with the actual crack development. Analysis of AE signals reveal that the CLC matrix cracking produces signals with less number of hits that lie in the notched plane in bending. Moreover, the signals from the post peak regime correspond to more number of hits which tend to be scattered around the plane of notch due to the fiber pull out.

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1. Introduction

Cellular lightweight concrete (CLC) is increasingly used in various low strength structural and non-structural applications due to its properties like low density, termite resistance, high thermal and acoustic insulation [1]. CLC is widely used in infill masonry construction, soil stabilisation, solid fills for hollow aluminium doors and window frames, thermal insulation on roof slabs, and in tunnel linings [2,3]. Moreover, CLC can be classified as sustainable and green building material due to the usage of high volume of fly ash during the manufacturing process [4]. The low carbon footprint involved in manufacture of CLC makes it an eco-friendly building material. However, the low tensile strength and brittle nature of CLC raises concerns when subjected to flexure, tensile and shear loading and limits its different applications.

Usage of synthetic fiber as a reinforcement in cellular concrete has increased in the recent years due to its ability to transform the brittle behavior of CLC into ductile under various modes of testing such as compression, flexure, tension, shear and impact [5]. Fiber reinforced CLC (FRCLC) is one such special concrete which has enhanced toughness, better composite behavior, durability

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and impact resistance compared to their unreinforced counterpart [6,7]. Improvement of mechanical properties of high performance concrete by addition of synthetic fiber reinforcement has been confirmed by many researchers [8–13]. Although steel fibers have superior mechanical properties compared to that of synthetic fibers, they decrease the workability and creates a balling effect at higher dosage. On the other hand, structural synthetic fibers, being non-corrosive and malleable, have gained attention in the recent years. They are also used for reinforcing cementitious materials to control the crack propagation and improve the overall structural performance [8,9]. Polyolefin fibers used in this study comes under the category of synthetic fibers. They are manufactured in two different types (a) Mono-filament and (b) fibrillated. Monofilament fibers have constant cross sectional area along its length. Fibrillated fibers are produced as films or tapes which can transform like net when mixed with concrete. Synthetic Polyolefin fibers can also be classified as micro or macro (structural) fibers. Micro-synthetic fibers are typically 12 mm long and 0.018 mm in diameter. Macro ones are typically longer (40–50 mm) and larger (0.3–1.5 mm) in size. Better bonding characteristics is now possible by the virtue of surface improvement on the fiber. Low density, better corrosion resistance and chemical inertness makes synthetic fibers a better choice for FRC when compared to the steel fibers. However, the low modulus of elasticity of synthetic fibers restricts them to be used as primary reinforcement. Nevertheless, these fibers can be used for special applications like cold storage walls, slab on-grade, ballast less subgrade track, tunnel linings and non-load bearing precast partition walls in high rise framed structures/ load bearing walls of appropriate thickness in low rise buildings. Therefore, it is important to understand the effect of fiber reinforcement on the fracture behavior of CLC to increase its wide spread usage.

It is worth mentioning that the synthetic plastic fibers used in this study are not green and a sustainable material. Use of natural fibers may be a sustainable option. Nevertheless, the fiber volume fraction used in this study is very minimum of up to 0.55%. This is relatively a low proportion compared to the volume of the matrix. In addition, recycled plastic wastes can also be used as fiber reinforcement in CLC. Besides, the synthetic fibers used in this study have well defined mechanical properties, which the natural fibers and other recycled fibers lack. Therefore, to reduce the variability in the experimental program, synthetic fibers with relatively low dosages are used.

Fracture parameters for CLC has been investigated in the past [14]. Indirect tensile strength, strain softening and fracture energy of different types of aerated autoclaved concrete (AAC) has also been reported [15]. Crack nucleation is a phenomenon where cracks at micro scale coalesce to from a macro crack, which eventually leads to the failure of concrete under flexure. The three dimensional region where this process happens is referred to as fracture process zone (FPZ) [16]. In particular, acoustic emission (AE) technique is used to quantitatively assess the crack growth in structural elements by correlating it with the AE hits encountered. It can be argued that the pores in the cellular concrete can hinder the propagation of elastic waves emanating from the crack source, thereby weakening the signal strength. This is true in case of porous concrete materials where the matrix media is predominantly disconnected. Whereas in cellular concrete material, the pore structure is disconnected. This makes the CLC medium continuous and does not hinder the wave propagation.

Attempts have been made in the past to qualitatively define the damage accumulation in concrete using acoustic emission (AE) technique [17]. Berthelot et al. [18] performed frequency analysis on concrete specimens to identify AE events by deducing its spectrum from detected signal. Sause and Stefan [19] modelled AE crack source using finite element modelling approach which calculates the dynamic displacement field during crack formation. Landis and Shah [20] conducted experimental study on flexural behavior of mortar beams to evaluate micro-crack parameters using AE technique. They found that the predominant mode of fracture in micro-cracks of mortar is mode II. Recent study has confirmed that AE activity increases with the amount of steel fiber reinforcement [21]. Qualitative fatigue crack classification on reinforced concrete beams was studied by Noorsuhada et al. [22]. Two indices of AE parameters were used and the relationship indicated the transition of crack mode corresponding to the damage development. Hu et al. [23] conducted fracture tests on notched concrete beams and illustrated that AE technique can be employed effectively to determine the crack propagation until the complete failure of specimen. In addition, they also noted that AE technique could help in obtaining the initial fracture load and unstable load at a slow loading rate. Cracking due to corrosion has been detected and located [24–30] using AE technique. Aggelis et al. [31] conducted the shear and tensile fracture test on cementitious materials by altering the loading equipment. It was observed that different modes of fracture process can be identified using AE technique. Aldahdooh and Bunnori [32] tested reinforced concrete beams under flexure and showed that the initial level of damage was associated with the tensile mode and gradually shifted towards shear mode of failure with increase in damage levels. The test results from AE technique has also been verified by researchers [33–35] using digital image correlation (DIC) technique. The focus of this investigation is to understand the fracture behavior of FRCLC under flexure. Notched FRCLC specimen were tested under three-point bending configuration with AE sensors attached on the surfaces. Generally, the AE sensors can range from 5 kHz up to 2000 kHz. Studies from past reveals that for studying normal concrete narrow band sensors are sufficient. However, no previous investigation has focused on understanding the CLC behavior using AE sensors. Any higher frequency waves cannot be captured with the use of only narrow band sensors. Finally, the analysis of the results shows that the average frequency lies in the range of 50 k Hz to 350 kHz. Therefore, two different kind of sensors results in overlap of frequency range of 200 kHz with a difference of ±50 kHz are used in this study. Crack formation modes can be distinguished into shear and tensile modes based on the two methods viz., Parameter based method and simplified Green function for moment tensor analysis (SiGMA) procedure [36].

In the recent years, continuous monitoring of structures in-service has been highlighted around the world. Thus, development of non-destructive evaluation (NDE) techniques for the inspection of concrete structures is currently in high demand. Varieties of innovative NDE techniques are actively under development in concrete engineering, which are closely associated with fracture mechanics. Fracture in a material takes place with the release of stored strain energy, which is consumed by nucleating new external surfaces (cracks) and emitting elastic waves. The latter phenomenon is defined as acoustic emission (AE). The elastic waves propagate inside a material and are detected by an AE sensor. By analyzing the detected signals, more useful information associated with the damage location and extent of internal damage can be assessed successfully. Thus, the AE technique can be a viable non-destructive and reusable tool compared to the conventional mechanical testing for health monitoring. Therefore, with proper calibration and in-depth scientific reasoning, AE technique can be an indispensable tool for non-destructive evaluation of new sustainable materials such as fiber reinforced CLC explored in this study.

2. Research significance

Number of investigation in the past have focused on understanding the behavior of fiber reinforced concrete using AE technique. However, the acoustic emission behavior of fiber

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