Applied Acoustics xxx (2016) xxx–xxx

Contents lists available at ScienceDirect

Applied Acoustics

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

Acoustic emission monitoring of reinforced concrete beams subjected to four-point-bending

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ARTICLE INFO

Article history:
Received 12 December 2015
Received in revised form 29 July 2016
Accepted 3 August 2016
Available online xxxx

Keywords:
Acoustic emission
Reinforced concrete beam
Parametric analysis
Crack classification
Damage classification and Gaussian mixture modelling

ABSTRACT

The aim of this study is to apply acoustic emission (AE) technique and study the damage mechanism of the reinforced concrete (RC) beams under four-point bending. Laboratory experiments are performed on three types of RC beams of grade M30 with 42, 64 and 93% of longitudinal steel against balanced section. The damage in the beams are classified into four zones symbolizing formation of micro cracks, visible cracks, steel yielding and concrete crushing. The AE parameters such as amplitude, rise time, count, duration and average frequency are quantified in each damage levels and a parametric analysis is performed between average frequency and RA value. The results showed that as the level of damage increased, the values of AE parameters such as count, hits, rise time, acoustic emission energy and duration increased except for average frequency. This results coincided with the visual observation results according to crack modes. The adequacy of the crack classification is also evaluated by Gaussian mixture modelling (GMM), a probabilistic based approach. GMM is used as a parametric model to overcome the randomness found in the data set generated by AE testing. The results of the present investigation can be utilized in health monitoring of concrete structures subjected to flexural load.

1. Introduction

The damage and deterioration in the existing concrete structures cause poor performance under service loading. This worsening is due to increased service loading, ageing, corrosion, fatigue, environmental hazards and environmental effects [15]. It is very important to understand phenomenon associated with cracking in order to maintain the structure both for safety and economic considerations [1]. At present monitoring of concrete structure is carried by destructive testing or non-destructive testing (NDT). Acoustic emission (AE), monitoring is a unique, non-invasive and passive NDT which is now widely accepted and is being used in the field of civil engineering for structural health monitoring. AE signals are diminishing elastic waves formed due to release of the energy in the material by propagating micro-damages. The damages are caused due to micro-crack growth, movement of voids, grain boundary sliding, crack initiation and development, phase changes in the crystalline structure [25]. It is to be noted that AE signals accompany only active damages that are initiated or developed during subjected loading conditions [9]. The advantages of AE technique are that the position of developing cracks can be determined and also the whole structure can be tested at once without intruding into any process associated with the structure [26]. AE testing characteristics can be used for both global and localized monitoring of damage portion. However one major drawback of using AE testing is unavailability of a standard procedure to use it in all types of the structures or bridges [18].

In general, classical or parameter-based technique or signal based AE technique is employed for monitoring structures [22]. AE techniques have been applied to detect the crack location, quantify the degree of damage and to determine the crack classification in concrete structures. It is found that peak amplitude, duration, frequency, counts, rise time, decay time, frequency spectra and polarity signal parameters are useful for better characterisation of the source of AE. The AE parameters are influenced by the type of loading, maximum aggregate size, and material characteristics [14,5,4,23]. Recently crack classification [3], damage evaluation [3] and damage classification [24] of reinforced concrete beams with varying thickness have been applied by AE technique. However, it is found that there is no universally accepted theory of fixing boundaries for crack classification in concrete structures due to the parameters like member geometry, material properties sensor location and response data. Recently probabilistic approach based methods, such as Gaussian mixture modelling [19,21] applied for damage identification and crack mode classification

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http://dx.doi.org/10.1016/j.apacoust.2016.08.006

in reinforced concrete structures have been found to overcome the deficiencies of conventional crack classification suggested by [22,7].

From the literature, it is noted that the studies based on prediction of crack pattern and behaviour of RC beam with varying percentages of tension reinforcement by employing AE technique is limited. The formation of cracks during bending of reinforced concrete beams are different and have different effects on signal propagation [13,17]. This motivates to take up the present study and understand the effect of reinforcement ratio in RC beam, in terms of AE output data and applying the same using GMM. The following tests will establish the potential for AE monitoring as a NDT technique in reinforced concrete structures.

2. Acoustic emission

In the present work research is focussed to highlight and quantify reinforcement ratio effect, by classifying crack formation with that of the visual observation from testing, using AE method. The active cracks in the concrete during testing are monitored are per JCMS-III B5706 [11] and RILEM Technical Committee [22] recommendations. In the AE testing, energy, count, duration, amplitude, rise time and threshold value are used for evaluation of damage process, shown in Fig. 1.

AE energy is the total elastic energy released during any event and considered as the area under the rectified AE signal. Count rate is defined as the number of times within the duration, when one signal exceeds a present threshold. AE count rate is also useful to provide the intensity of the AE event. Duration is the time difference between the first and last threshold crossings. Rise Time is defined as the delay between the onset and the maximum amplitude over the amplitude. The cracking modes of reinforced beam during testing are corroborated by evaluating the RA value and Average frequency (AF). RA value is defined as the ratio of rise time by the amplitude and measured in μs/V. AF is defined as the ratio of threshold crossing by the duration and measured in kHz. From this two parameters, cracks are classified into tensile and shear cracks as shown in Fig. 2. This crack classification method is based on the JCMS-III B5706 [11].

3. Experimental procedure

3.1. Materials and mix proportion

The constituents include 53 grade Portland cement of ASTMC150/Type I, fine aggregate/standard sand as per Indian Standard 650-1991, coarse aggregate with a maximum size of 20 mm, steel reinforcement with a specified yield strength of 415 MPa and ordinary tap water. The mix is designed as per American Standard ACI 318 code, for the reinforced concrete grade M30. This include a cement of 393 kg/m^3; natural river sand 888 kg/m^3; coarse aggregate 923 kg/m^3 and water/cement ratio of 0.50. Typical mechanical properties for the plain concrete are: compressive strength = 35 MPa (in accordance with ASTM C109) and split cylinder strength = 4 MPa (in accordance with ASTM C 496 M - 11).

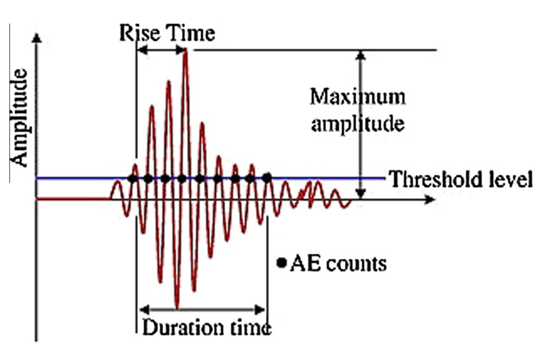

Fig. 1. Acoustic emission parameters [14].

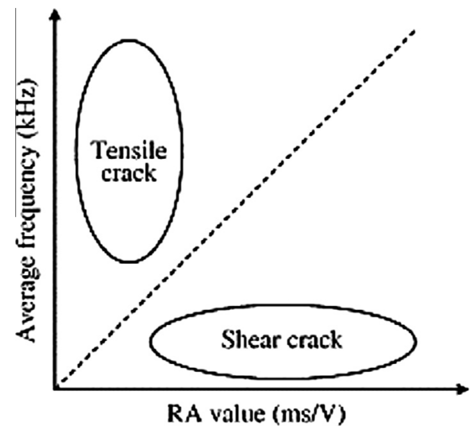

Fig. 2. Crack classification [14].

Table 1
Details of the Control Reinforced Beams.

Beam type	Beam dimension (mm)	Tension reinforcement	Reinforcement ratio (%)
A	100 × 200 × 1500	2 no.'s 8 mm	0.570
B		2 no.'s 10 mm	0.897
C		2 no.'s 12 mm	1.299

3.2. Samples preparation

Under-reinforced RC beams are designed to fail in flexure. Three types of beams A, B and C each 4 in numbers are cast. The details of the beam are given in Table 1. Beams are cast having overall dimension of 100 mm wide, 200 mm depth, and 1500 mm length. The characteristic strength of the steel (fy) is 415 N/mm^2. Three types of reinforcement ratios considered for the study are 0.570% (A), 0.897% (B) and 1.299% (C), which forms 42% (A), 64% (B) and 93% (C) of longitudinal steel against balanced section. Reinforcement ratio is the ratio of area of longitudinal reinforcement to area of cross section. A, B and C beams. Two numbers of 12 mm, 10 mm and 8 mm diameters of steel rod is provided as tensile reinforcement in A, B and C. 2 no.'s of 6 mm diameter steel is used as tie bars and stirrup is placed at 125 mm c/c distance to avoid shear failure. All beams are cured in water having a temperature of 26 ± 2° C, till the date of testing (after 28 days).

3.3. Test set up and AE system

All the control beams and retrofitted beams are tested under four-point loading. The centre to-centre span between supports is 1200 mm. The load is applied under a displacement rate of 0.5 mm/min by a 500 KN servo-controlled hydraulic actuator, shown in Fig. 3. The tested beams are instrumented with three transducers placed at mid span and loading point. Prior to the casting of the specimens, 5 mm gauge length strain gages are affixed on both flexural and shear reinforcement to know whether steel is yielded. Strain gages are fixed at 1/3rd from both the sides and at mid span on the flexural reinforcement. Specimens are white washed and grids are marked on two sides of surface of beam. The size of grids is 50 mm × 50 mm. The grids are marked on specimen for purpose of locating the progression of the crack. The AE system consists of data acquisition board, software for signal pro-