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Crack Classification in Notched Concrete Beams using Acoustic Emission Technique

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Abstract: **— Cracking of concrete is a major serviceability problem in reinforced concrete (RC) structures. Linear fracture laws and strength based theories are limited in application to concrete because of the sizeable fracture process zone and the inelastic growth of crack openings and crack length. In order to build sustainable structures, the study of fracture mechanism is necessary. As concrete is generally classified as quasi-brittle material, which is a heterogeneous and multiphase material, the fracture process is very complex since it consists of main cracks with various branches like primary and secondary cracks and micro-cracks. It is necessary to obtain more data describing the characteristics of fracture such as types of cracks so that, adequate steps can be taken to control and prevent the failure in concrete structures. Thus, the present paper enlightens the applicability of Acoustic Emission (AE) technique for classification of cracks developed in beams subjected to three point loading. The experimental results indicate that RA value analysis of AE technique is a powerful technique.**

***Index Terms*—Acoustic Emission, Concrete Beam, Fracture Mechanics, Notch**

I. INTRODUCTION

Fracture mechanics is mechanics of solids containing planes of displacement discontinuities (cracks) with special attention to their growth. When a crack length reaches a certain critical length, it can propagate, even though the average stress is much less than the tensile strength of the test specimen. Fracture mechanics tries to find the quantitative relations between crack lengths, material's resistance to crack growth, and the stress at which cracks start to propagate [1].

A very important aspect of fracture testing is crack detection. Without having some insight in the physical mechanisms of crack growth, fracture mechanics becomes meaningless. Characteristics of fracture such as type of crack, energy released during cracking, fracture process zone etc are important to study. In order to avoid harmful changes in structural element many monitoring methods have been developed to evaluate damage before reaching the critical level. One effective method could be non destructive testing (NDT) which is practical and useful in laboratory test as well as on-site measurement. A number of NDT techniques are available for crack detection like pigmentation, X-ray diffraction analysis, microscopy observation; ultrasonic speed measurement each will have its own virtues and deficiencies [3]. These techniques can only observe the surface of the specimen and there are unable to do three dimensional analysis of fracture. Acoustic Emission (AE) technique which is one of the non-destructive techniques has been also used to study the cracks and properties cracks [3]. The advantage about AE technique is that the damage state can be related to AE parameters, which can be used to estimate the extent of damage [4].

The term AE is commonly used to describe both a technique and the phenomenon upon which the technique is based. AE can be defined as a class of phenomena whereby transient elastic waves (ultrasonic frequency range) are generated due to rapid release of energy from a localized source within a material [4]-[5].The AE monitoring technique uses one or more sensors to 'listen' to a wide range of events that may take place inside a solid material.

AE parameters such as frequency, duration, amplitude, count and rise time during different stages of cracking are by [4] noticed which gives the results to distinguish different cracks in RC beams and extend them for field applications. On the other hand, AE parametric analysis has been also applied to crack classification based on the JCMS-III B5706 code [7].According to [8] AE parameters such as RA value and average frequency is obtained from rise time, maximum amplitude, AE count and duration time. From these two parameters, cracks are readily classified into tensile and shear cracks. In [9] researcher classified the cracks in the RC beams with varying thicknesses based on the fracture mechanism of the RC beams and the AE signal features. This paper attempts to indicate the ratios of flexural and shear cracks at each level of damage.

The present study aims to classify the cracks in notched plain concrete and reinforced concrete beams using AE technique and to compare the interpretation of measurements under external loading condition.

II. ACOUSTIC EMISSION TECHNIQUE

a. Introduction

The AE technique has been widely used in the field of civil engineering for structural health monitoring [10]. Compared with other non-destructive techniques, the AE technique can give valuable information on activity happening inside the material and it has capability of on-line monitoring during service of structures or facilities. Other than that, the AE technique also offers the possibility of capturing the damage process with regard to the time and position of its occurrence [1].

The sources of AE are the deformation processes including crack growth and plastic deformation [3]-[11]. The stress wave released propagates through the solid due to the energy release during the deformation process. Amount of energy released depends upon its size and rate of local deformation process.AE is usually dealing with high signal rates and events at relatively high frequencies (most of the released energy from 1 kHz up to several megahertz) [1].

b. Instruments used for AE testing

The process of AE monitoring involves specific instruments, each having a unique role to play and is essential to ensure proper monitoring [1]. It includes sensors, couplants, pre-amplifiers and data acquisition system as shown in Fig. 1.

AE sensors are the key instruments which detect mechanical transient waves generated from a defect structure and convert them into electrical AE-signals. Usually, piezoelectric resonant sensors are used for AE testing [5].Localized energy release gives rise to elastic waves that are detected by transducers (sensors) attached to the surface of the specimen provided, the waves are of sufficient amplitude. When cracks grow in a material, the localized strain energy is released. The released strain energy originating from growing cracks is detected by means of sensors [5].In the present study, R3α type sensor is used where the diameter of sensor is 19mm and height of sensor is 20mm.

Sensors are fixed to the surface of the material to be tested using couplants. These couplants are mainly help in easy and complete conduction of acoustic waves generated from the source. Commonly used couplants are oil, glue, high vacuum grease; etc [5]. But for the present work grease is used as couplants. Application of couplant layer should be thin, so it can fill gaps caused by surface roughness and eliminate air gaps.

Mechanical waves coming from sensors are then transfer to preamplifier. The main purpose of a pre-amplifier is to boost signals to a less vulnerable level and effectively filter and reject noise from areas outside the sensor operating range. Modern AE systems use computers and appropriate software for data acquisition. All the signals received at the sensor, end are acquired and stored in the acquisition system [5].

A typical AE-signal (or wave) which includes AE duration, rise time, AE amplitude, AE energy, counts, hit etc is shown in Fig. 2

c. AE parameter analysis

Final goal of monitoring AE phenomena is to provide beneficial information to prevent fatal fracture, by correlating detected AE signals with growing cracks.AE signals due to formation of cracks are detected by AE sensors attached on the surface of the concrete specimen. Such some AE parameters like number of hits, count, duration time, amplitude, energy, and rise time are recorded by AE measurement system. In concrete materials, the classification crack type is proposed using the combination of average frequency and RA value. In order to classify active cracks, AE parameters such as rise time and maximum amplitude are applied to calculate RA value.

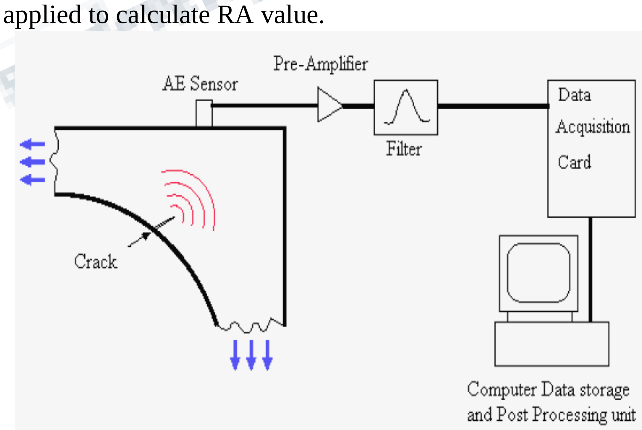

Fig.1 Schematic representation of AE monitoring [15]

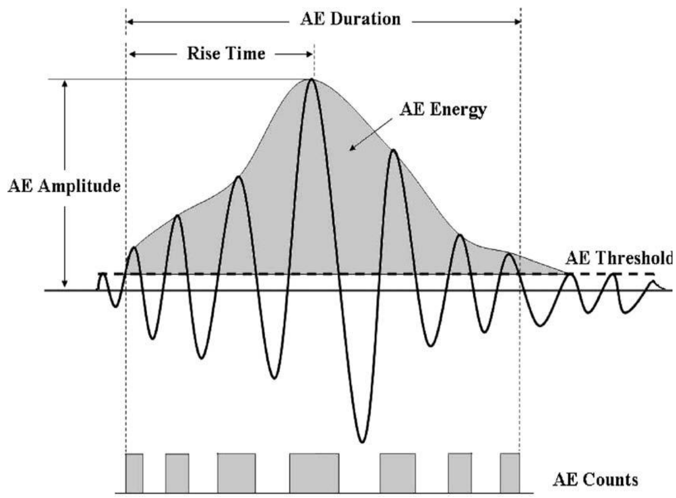

Fig.2 Parameters of a typical AE-signal [1]

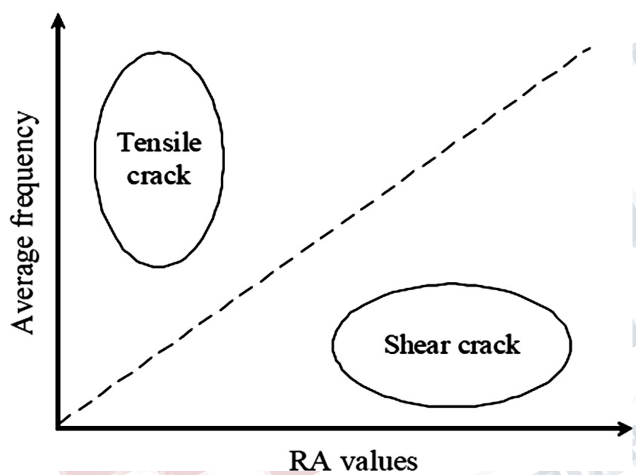

Fig.3 Classification type of cracking [7]

The average frequency is obtained from AE count and the duration time as formulated using equations (1) & (2).

RA value= Rise time/ maximum peak amplitude (1)

Average frequency=Count/duration time (2)

From these two parameters, cracks are readily classified into tensile (mode I) and shear cracks (mode II) as illustrated in Fig. 3. A tensile type crack is referred to as an AE signal with high average frequency and low RA value similarly in the opposite way a shear type crack is identified [12].This crack classification method is based on the JCMS-III B5706 code [7], of which results were confirmed under the four-point bending tests and the direct shear tests of concrete specimens.

III. METHODOLOGY

a. Material and mix proportion

Tests were carried out on PC and RC beams having dimension 150x250x700mm and designed as per IS 456:2000 code [13] and IS 10262:2009 [14] for grade M35.Ordinary Portland Cement (OPC) having specific gravity of 3.15 is used for preparing the specimens. River sand passing through 4.75 mm sieve, having specific gravity of 2.58 is used as fine aggregates. Crushed stones having maximum size of 20 mm and specific gravity of 2.74 are used as coarse aggregates. RC beams are reinforced with two number of steel bar having diameter 16 mm and grade Fe 500 with 50 mm cover from the longer sides as well as from bottom of specimen.

A notch is introduced at the middle of beam during the casting process itself by inserting a steel strip of 5 mm thick and 25 mm in depth as shown on the Fig. 4. The purpose of providing notch is to impose the position of fractured section so that the cumulated locations of acoustic events are centered at notch. The notch had a width of 5 mm at its tip, which is less than 10 mm as suggested by RILEM FMC 50 [2].

The compressive strength of the cubes at 7 and 28 days was found to be 25.6 MPa and 35.5 MPa respectively. Whole experimental procedure is divided into three sets, each set comprises of three PC and RC beams having notch. Three specimens were cast at each set. After demolding at the age of 1 day, specimens were cured in water for 21 days.

b. Experimental setup

All the beams were tested under three point loading to examine the flexural behavior and level of damage using AE technique as shown in Fig. 5. Tests were conducted on universal testing machine (UTM) having capacity of 1000 kN.

The surface of specimen where the positions of the sensors were marked was initially cleaned. Two sensors were mounted on the top of the beam having distance 200mm from support using a clamp mechanism as shown in the Fig. 5. AE sensors of type R3α were fixed to the specimen surface using special vacuum grease/gel. In between specimen and sensor, aluminum sheet is provided. Aluminum sheet below sensor is used to avoid the wear and tear of face material sensor as the concrete surface generally appears to be rough. The sensors were initially tested for their sensitivity by pencil lead break test. The AE threshold was set to 45 dB.

During test the beams were simply supported with a span of 600mm. Three point bending load is applied at the center of the beam at a loading rate of 4 kN per minute. Beam is loaded up to failure and entire test is monitored with a dedicated AE acquisition system.

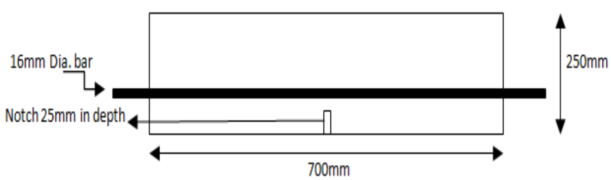

Fig.4 Crossectional view of RC beam having notch

Fig.5 Experimental setup

IV. RESULTS AND DISCUSSION

During the experimental test various AE parameters were recorded through AE software which are further analyze as discussed below. From the AE data obtained, the numbers of hits until failure were recorded.

For PC beam

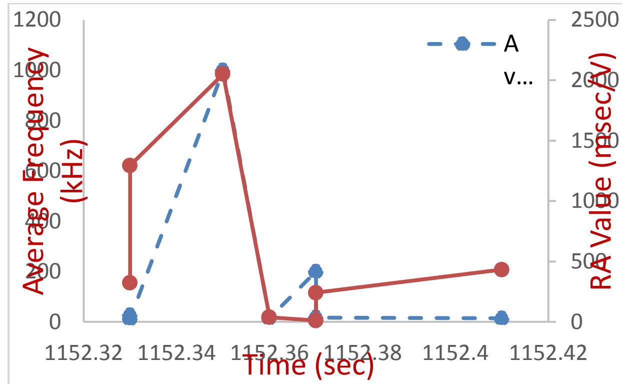

Fig.6 variation of avg. Frequency and ra value w.r.t. Time for pc beam

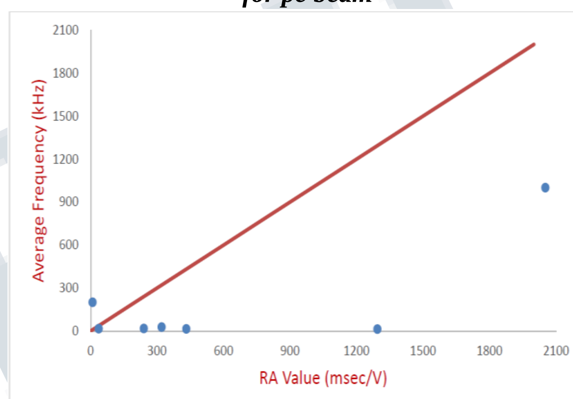

Fig.7 Avg. frequency vs. RA value graph for PC beam

From AE output data, RA value and Avg. frequency is calculated using equations (1) and (2) and graph is plotted as shown in the Fig.7 for PC beam. Out of total cracks identified, 14.28% are found to be tensile (mode I) cracks and 85.72% are shear (mode II) cracks.

By using AE output data, the graph of variation of Avg. frequency & RA value w.r.t. time is plotted as shown in Fig.6. At 1152.37 sec. of testing indicates RA value is low and average frequency is high which indicates the presence of tensile crack. In other case RA value is high and average frequency is low which indicates the presence of shear cracks.

For RC beam

From AE output data, RA value and avg. Frequency is calculated using equations (1) and (2) and graph is plotted as shown in the fig.9 for RC beam. Out of total cracks identified, 16.67% are found to be tensile (mode i) cracks and 83.33% are shear (mode ii) cracks.

From output data, the graph of variation of Avg. frequency & RA value W.R.T. time is plotted as shown in Fig.8. At 1178.56 sec. of testing indicates RA value is low and average frequency is high which indicates the presence of tensile crack. In other case RA value is high and average frequency is low which indicates the presence of shear cracks.

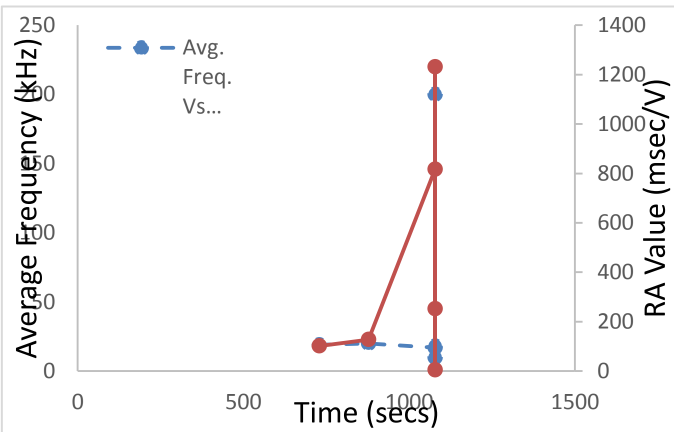

FIG.8 VARIATION OF AVG. FREQUENCY AND RA VALUE W.R.T. TIME FOR RC BEAM

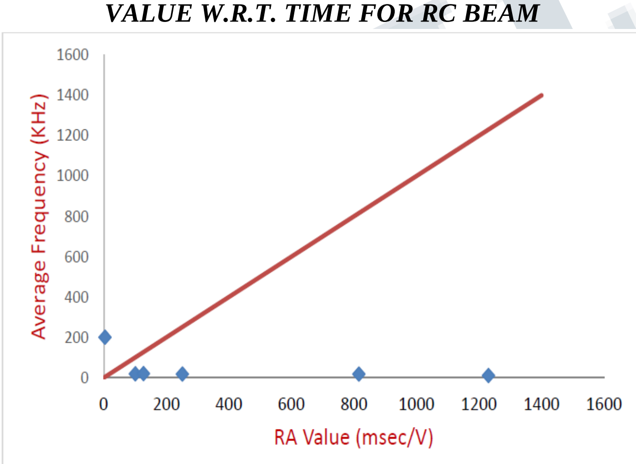

Fig.9 Avg. frequency vs. RA value graph for RC beam

V. CONCLUSION

The present experimental work investigates behavior of PC and RC notched beams under three point bending test using AE tech. From the experimental work following conclusions can be drawn.

1. Time between formation of crack and final failure of beam is observed to be more in RC beam in comparison to that of PC beam. This may be due to the presence of reinforced steel in RC specimen.
2. Percentages of tensile cracks as well as shear cracks are same in both the specimens.
3. AE parametric analysis is powerful technique to identify and classify the cracks in concrete structures.

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