Crack classification in concrete beams using AE parameters

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Abstract. The acoustic emission (AE) technique is an effective tool for the evaluation of crack growth. The aim of this study is to evaluate crack classification in reinforced concrete beams using statistical analysis. AE has been applied for the early monitoring of reinforced concrete structures using AE parameters such as average frequency, rise time, amplitude counts and duration. This experimental study focuses on the utilisation of this method in evaluating reinforced concrete beams. Beam specimens measuring 150 mm x 250 mm x 1200 mm were tested using a three-point load flexural test using Universal Testing Machines (UTM) together with an AE monitoring system. The results indicated that RA value can be used to determine the relationship between tensile crack and shear movement in reinforced concrete beams.

1. Introduction
The deterioration and damage in existing concrete structures could be caused by ageing, fatigue, corrosion, environmental hazards and environmental effects [1]. Thus, it is a priority to detect structural damage through regular inspection and maintenance. In addition, it is very important to understand the phenomenon associated with cracking in order to ensure safety and cost efficiency [2]. Traditionally, visual inspection has been used by trained instructors to monitor bridge structures. Due to the limitations associated with visual inspection, it is impossible to detect all sources of damage especially for internal structures [3]. Therefore, it is important to facilitate asset management by improving or using more efficient techniques in the evaluation of reinforced structures.

Nowadays, the monitoring of concrete structures is carried using destructive testing or non-destructive testing (NDT) methods. One of the NDT techniques currently being investigated for reinforce concrete beams and bridge management systems is acoustic emission (AE). The acoustic emission (AE) technique is widely accepted in order to create non-invasive and passive NDT and is being used in the field of civil engineering for structural health monitoring [4]. Using this technique, elastic waves are released during the propagation of cracks [5,6]. The elastic waves propagating inside the material are detected by a piezoelectric transducer as shown in figure 1. A piezoelectric transducer is an AE sensor which is also known as the heart of the AE system as it converts stress waves into electric signals [7]. Prior to testing, the AE sensor network is mounted on a flat surface of the RC structure to detect the propagating waves. Using timing strategies, the source of the emission could be identified [8]. The sensor has to be mounted on the flat surface of an RC structure due to the flat frequency response. A rough surface would cause the AE sensor to be less sensitive and make it difficult
to detect AE signals [7]. In addition, grease can be used in order to improve the sensitivity between the concrete surface and that of the AE sensor. According to [9], grease is able to reduce the duration of the test by improving the surface contact between concrete and the AE sensor.

![Figure 1. Detection of acoustic emission wave [10].](image)

Even though the AE technique has been extensively utilised in damage monitoring for RC structures, there has been a lack of research on damage evaluation and correlating AE parameters. AE parameters are useful for better characterisation of AE sources such as peak amplitude, duration, frequency, counts and rise time. From the AE parameters, the rise time and amplitude can be used to define the RA value. The RA value can be calculated using equation (1) and equation (2):

\[ RA = \frac{Rise\ time}{Amplitude} \]  

\[ Average\ frequency = \frac{Counts}{Duration} \]  

The cracking behaviour of AE parameters could be classified into two types of fracture mode namely tensile crack and shear movement. Tensile cracks (Mode I) are nucleated during the early stages of the damage process. On the other hand, shear movement (Mode II) is generated when fretting or sliding occurs to existing cracks [7]. These types of crack classifications are indicated in figure 2. According to Aggelis et al. [11], the emission during the early stage has shown that the result corresponds to tensile cracks whereas the pattern of emission exhibits a high average frequency and low RA values. In contrast, during the later stages, shear cracks occur close to failure which indicate the value of average frequency. [2]. Hence, classifying the type of cracking behaviour in RC structures requires a combination of the average frequency against the RA value as shown in figure 3.
2. Experimental program
The experimental program in this study consists of the preparation of beam specimens, acoustic emission measurement and flexural testing.

2.1. Preparation of beam specimens
The specimens were reinforced concrete beams with a dimension of 150 mm x 250 mm x 1200 mm each. They were designed in accordance with Eurocode 2 (BS EN 1992-1-1:2004) as shown in figure 4. The beams were reinforced with steel bars with high tensile strength. Cement, water, fine aggregate and coarse aggregate were used to make the beam specimens. The concrete mix was then casted into moulds. The vibration of fresh concrete was done in order to avoid the formation of voids or pores within the concrete specimen. In order to ensure that the design fulfilled the required strength, three cube specimens measuring 150 mm x 150 mm x 150 mm were prepared with grade G30 cement. These specimens had to undergo a compression test after a curing period of 7 days and 28 days respectively to gain uniform strength. Prior to the test, the surface of the beam specimens was smoothen to ease the installation of AE sensors.
Figure 4. Beam cross section dimension and detail reinforcement.

2.2. Acoustic emission measurement
An acoustic emission system board (8 channels) x 16 (hubs) bit acoustic emission channel were used for the AE measurement. During the test, AE was monitored using a MicroSAMOS (μSAMOS) supplied by Physical Acoustic Corporation (PAC). Four sensors (R6I-AST) for concrete materials were mounted on the beam surface at selected points shown in figure 5 by using a coupling agent [13]. Magnetic clamps were used to safeguard the sensor where the sensors were held in place by magnetic clamps [13,14]. The sensitivity of the AE sensor installation was verified using the Hsu-Nielson method. The sensitivity of the sensors were checked before the specimens were tested. The sensors are significantly coupled if three or more replicates of pencil lead fracture (PLF) produce an amplitude of 99 dB or the sensitivity is within ±3 dB in difference [15,16]. This is done to ensure that the sensor and the beam have good contact in order to provide accurate results throughout the test. If these criteria are not met, the sensor on the beam surface will be remounted and the sensitivity check has to be carried out again until the amplitude fulfills the requirement. The threshold level was set to 45 dB to eliminate noise from the surrounding area [10,17,18].

2.3. Flexural testing
The simply supported specimens were tested under three-point load flexural testing by using a Universal Testing Machine (UTM) loaded statically until failure, as shown in figure 5. Flexural testing was monitored using an AE monitoring system [19,20]. Six different load ranges used during the text, LR1 to LR6, are shown in figure 6.

Figure 5. Experimental setup with three-point flexural testing.

3. Results and discussion
The AE data parameters were analysed post-test using RA value methods to classify the type of cracking in the RC beam.
Figure 6. RA value analysis for each load range (a) LR1(0-21 kN) (b) LR2(21-40 kN) (c) LR3(41-60 kN) (d) LR4(61-80 kN) (e) LR5(81-100 kN) (f) LR6(100 until failure).
The RA value was assessed by using equation (1) and equation (2) to classify the type of cracking mode present in concrete beams. Thus, the analysis was done for each specimen using RA values. In figure 6, the results of the RA value analysis are presented according to the load range (LR). Figures 6(a) to 6(f) present the typical development of the cracking process from LR1 to LR6.

During the initial stage, as shown in figure 6(a), micro-cracking appeared at the middle section of the reinforced beam when loads ranging between 0 kN to 20 kN (LR1) was applied. This type of cracking is classified as tensile cracking. At this time, the damage mechanism is not too obvious as the steel bars begin to bear the load [2]. Next, figure 6(b) shows that when a loading range between 21 kN to 40 kN was applied to the specimens, tensile cracks continue to grow. At the same time, some diagonal cracks were formed between the support and point of loading.

After that, when LR3 was applied as shown in figure 6(c), the tensile cracks grew slowly between the two points of loading and the cracks propagated to the compression zone [12]. As shown in figures 6(d) and 6(e) where LR4 and LR5 were applied respectively, diagonal shear cracks spread upward when fretting or sliding occurs to existing tensile cracks. The tensile cracks continue to grow along with some diagonal shear cracks.

In figure 6(f), the tensile cracks did not spread to the top when LR6 was applied. Instead, diagonal shear cracks were formed at the beam support which spread upwards until the specimen failed.

4. Conclusion
This experiment has successfully identified the crack classification using AE parameters such as amplitude, rise time and average frequency. RA value analysis was employed. It can be concluded that the acoustic emission (AE) technique can be applied to monitor the progress of deterioration progress in reinforced concrete beams under loading in laboratory tests. Thus, AE parameters can be used for crack classification.

The RA value method analysis is suitable and effective for the typical crack classification process from initial damage to failure. On the other hand, it was confirmed that when the average frequency increases and RA value decreases, damage mode I (tensile cracking) occurs. Damage mode II (shear cracking) occurs when the average frequency decreases whereas the RA value increases.

From the RA value analysis method, the initial phase of loading causes tensile cracks. Nevertheless, when the loading increases, shear cracking occurs.

In conclusion, this experimental study provides a promising method for the classification of cracks in reinforced concrete beams using AE parameters.

5. References
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