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RA CLUSTERING (RAC) METHOD FOR ACOUSTIC EMISSION SYSTEM ON CONCRETE STRUCTURE

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ABSTRACT: This study introduces the use of acoustic emission (AE) monitoring for damage diagnostic is typically challenging due to the difficulties associated with discrimination of AE parameters to analyze the RA value. The difficulties still exist in using the AE technique for monitoring applications particularly in analyzing recorded AE data due to the large quantity of data involved. In this paper, the RA value clustering (RAC) method was utilized to classify the type of cracking on reinforced concrete beam specimens monitored by AE technique. To verify the crack classification of Rising Amplitude clustering (RAC) by using the NI LabVIEW clustering algorithm. Hence, the purpose of this research is to obtain the crack classification by using the RA clustering analyzing (RAC) method. It was found that the result by using (RAC) analyzing method was the reliable system to cluster the cracking on the RC beam. In addition, these analyzing system could use in many different sizing of the beam.

Keywords: Acoustic Emission, Clustering, NI LabVIEW, RAC method, Concrete Beam

1. INTRODUCTION

Non-destructive testing (NDT) is widely used nowadays especially for continuous real-time monitoring systems with minimum labor involvement as well as forensic engineering. According to L. Farbaneic et al [1], civil engineering is a field in which the use of NDT was developed. Acoustic Emission (AE) is an NDT testing technique with several unique features including real-time monitoring, high sensitivity, global monitoring capability and source location [2-3]. In this study, Acoustic emission (AE) was used in the localization of damage in composite and RC structure [4], crack detection [5], prediction of delamination in composite structures and damage assessment.

In comparison with other NDT technique, this AE technique is an effective tool to evaluate the structure and capable of locating the developing cracks without destroying the material condition and function of the structure. It also enables early crack detection as it has very high sensitivity to crack growth [6]. Two types of crack classification methods were introduced for tensile cracks (mode I) and shear cracks (mode II). AE parameter signals including amplitude, duration, count, hits, energy and rise time are important to determine the type of cracking. The AE signals were analyzed using the RAC value method. This is done to obtain the movement cracking of the structure as well as the damage crack classification.

AE signals contain a lot of information on the damage mechanisms during the monitoring stage. A major issue that arises for the AE technique is the difficulty in discriminating AE parameters due to the different damage mechanisms without using conventional methods [7]. Cluster analysis is generally used to separate or classify a set of parameters into several classes reflecting dataset internal structure. The clustering method using the NI LabVIEW software was used as a tool to reduce data redundancy and to optimize AE signal parameters. The clustering method can efficiently distinguish different types of cracking. The clustering algorithm is one of the most commonly used clustering methods where the data which belongs to a definite cluster cannot be included in another cluster [8]. In this study, the clustering method is used to supervise and analyze AE signal data for RC beam.

2. EXPERIMENTAL PROGRAM

The experimental program in this study consist of the specimen preparation, acoustic emission instrumentation and flexural testing.

2.1 Specimen Preparation

The prepared normal concrete was cast and poured into the beam molds with dimensions of 150 mm x 250 mm x 1200 mm. Thereafter, the vibration of fresh concrete was done in order to avoid the formations of pores within the concrete specimens. The specimens were reinforced concrete beam with steel bars with high tensile and designed by following Eurocode 2 (BS EN 1992-1-1:2004) as shown in Fig. 1. To ensure the design fulfilled the required strength, three cube specimens measuring 150 mm x 150 mm x 150 mm were prepared with grade C30. 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 smoothened to ease the installation of AE sensors.

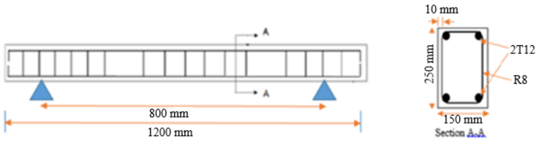


Fig. 1 Beam cross-section dimension and detail reinforcement.

2.2 AE Measurement and Processing

In the AE signal analysis, the most commonly used measurement parameters are amplitude, counts, duration, rise time and energy. In addition, the analysis of the AE parameters namely RAC method was used to know the crack classification in the specimens. The measurement set-up of AE was used as an AE system on a board 8 channel (PCI-8). During the test, AE was monitored using MicroSAMOS system (µSAMOS) provided by Physical Acoustic Corporation (PAC). The type of sensor which is R6I-AST have been attached on the beam surface at the selected point shown in Figure 2 and a thin intervening layer of coupling agent between the transducer and the specimen is usually used [9]. The typical AE sensor also has a case with a connector for a signal cable attachment. The case provides an integrated mechanical package for the sensor components and may also serve as a shield to minimize the interference noise [10].

Prior to AE testing, it is important to ensure that all the sensors are correctly mounted. Poor mounting the sensor will reduce the sensitivity and lead to loss of significant AE data. The sensor mounted sensitivity was confirmed according to ASTM E 976 (1999), by using a Hsu-Neilson source. A minimum of three lead breaks at the prescribed position was made on the test specimens. If the sensor produces a low signal amplitude reading which is below 97dB, the sensor sensitivity must check again until the amplitude fulfill the requirement [11]. The threshold level was set to 45 dB to eliminate noise from the surrounding area [11,12].

Fig.2 Experimental set-up with three-point flexural testing.

2.3 Flexural Testing

The flexural test was used to test the effects on the beam and prism specimens when loading is applied. A three-point bending test is illustrated in Figure 3 and the testing procedure was followed ASTM D790. A flexural test is used to test the tensile strength or flexural strength of concrete beams [13,14]. The tensile strength of concrete is important for finding out the rate of loading resisted by concrete before cracks occur [15] [16]. The purpose of the test is to apply to load to the beams. This is because an AE test is primarily for the monitoring of beam failure.

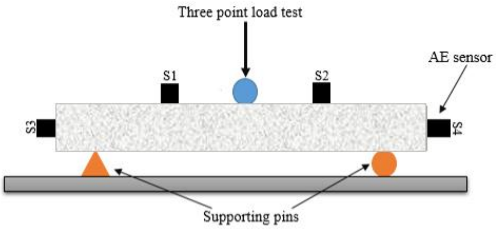


Fig. 3 Diagrammatic experimental setup of a three-point flexural test.

In this research, all the RC beams were tested under three-point loading to induce all kinds of damage mechanisms. The experiment was carried out until specimen failure occurred. During the RA value analysis, the loading phase was divided into six different load ranges from load range (LR) 1 to load range (LR) 6. All six load ranges are shown in Table 1. Table 1 represents the loading for every load range from LR 1 till LR 6. This load range distribution was made due to shows the phase of changes cracking.

Table 1 Load range analysis.

Load range	Loading
1	0 – 20 kN
2	21 – 40 kN
3	41 – 60 kN
4	61 – 80 kN
5	81 – 100 kN
6	101 until failure

2.3 AE Set-up

AE refers to the detection of ultrasonic signals through the use of a piezoelectric transducer attached to the surface of the structure that is monitored [17]. As defined by [12], the basic principles of AE testing are as follows; (i) application of load to produce mechanical tension; (ii) source mechanisms to release elastic energy; (iii) wave propagation is elastic energy which travels as a wave from the source to the sensor; (iv) the sensor converts the mechanical wave into an electrical AE signal; (v) acquisition of measurement data is the electrical signal that is converted into an electronic data set; (vi) display measurement data and (vii) evaluation of analysis [18] [19] [20].

Figure 4 shows the AE equipment set-up for laboratory testing [21]. Firstly, when the loading is applied to the RC structure, the cracking within the specimen was captured by the AE sensor attached to the surface. Then, the raw signal is passed through a pre-amplifier for pre-amplification and then to the data acquisition system. The number of AE hits is then detected. Finally, the acquired data is digitized and fed into the AE computer for data storage, display and analysis. During the analysis, crack classification was conducted via the RA value and RA clustering method.

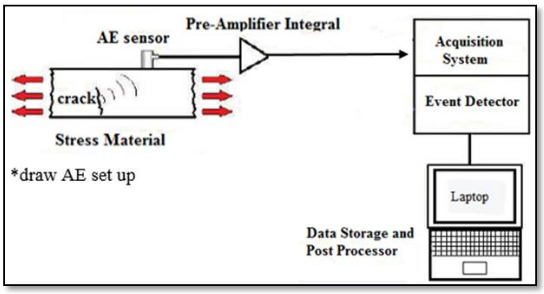


Fig. 4 Acoustic Emission equipment set-up.

3. DEVELOPING RAC METHOD

The National Instrument Laboratory Virtual Instrument Engineering Workbench (NI LabVIEW) is a system engineering software for applications that require testing, measurement, and control with rapid access to hardware and data insight [22]. LabVIEW reduces the complexity of programming and is able to focus on unique engineering problems. In this research, NI LabVIEW was used to analyze the RAC method in order to classify AE sources and to find out the types of cracking taking place in RC structures [23] [24]. AE parameters such as the average frequency and the RA value were used. This RAC method was developed using NI LabVIEW and actual data from the AE sources. In this point, the development of RA clustering is explained. Figure 5 to Figure 11 shows the steps to develop the RAC system. Firstly, create a blank VI and save the VI as RAC analysis. In Figure 5, a case structure was created in the block diagram due to system grouping such as an open file, run data from AE source, display XY graph, add a column for the cluster, create cluster, description and stop the program. The data propagates from the left to the right and starts with colors coded representations of input variables from the front panel controls.

From Figure 6 the table control is added to enable easy access to the specimen data. The file was set as CSV. Later, the system reads the data in the index array. To display the XY graph, the index array must be inserted again by removing the header to obtain the RA value and average frequency as shown in Figure 7. After the input is added, the system must create a case structure for clustering the data from AE sources and create a clustering formula as presented in Figure 8 and Figure 9.

In order to make this system better than conventional methods, a description was created to show the total amount of AE data and the major types of cracking. It was also created to stop the system after the clustering is complete, as represented in Figure 10 and Figure 11.

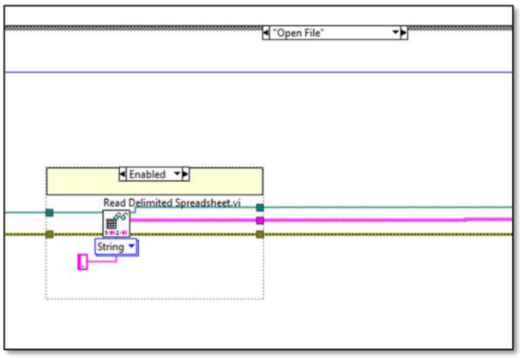


Fig.5 Block diagram for the open file.

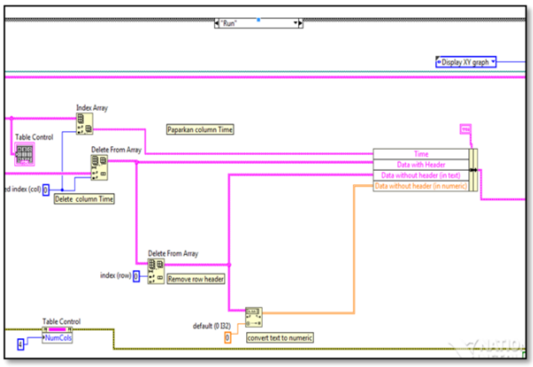


Fig. 6 Block diagram for run the AE data.

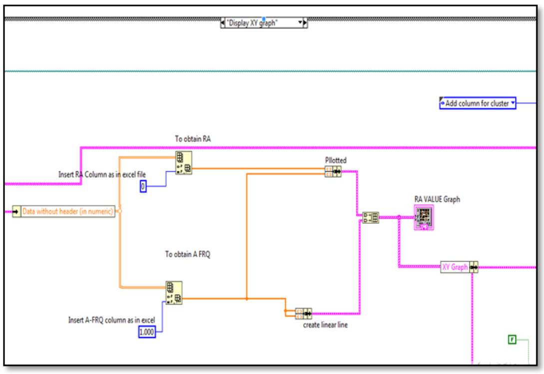


Fig. 7: Block diagram for display the XY graph.

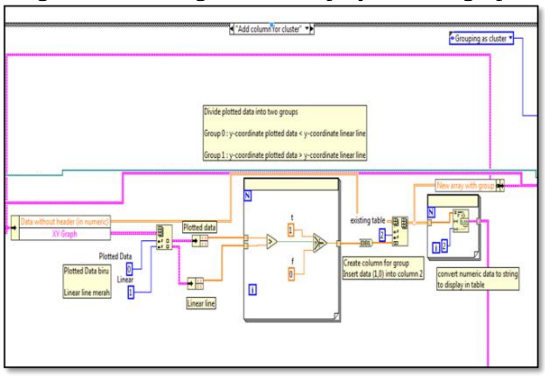


Fig. 8 Block diagram for formula cluster.

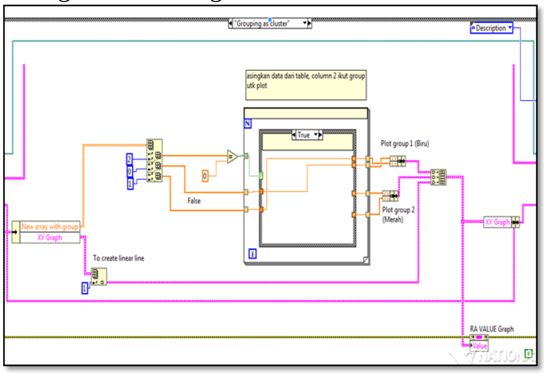


Fig. 9 Block diagram for cluster system.

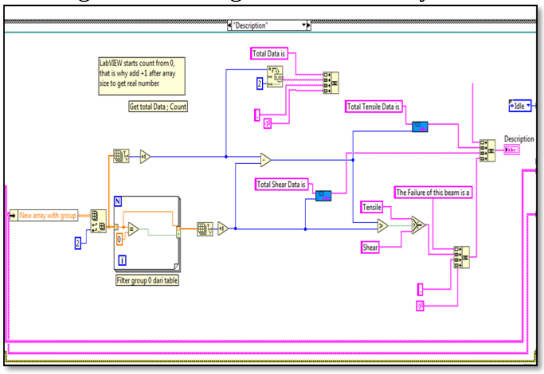


Fig. 10 Block diagram for adding a description.

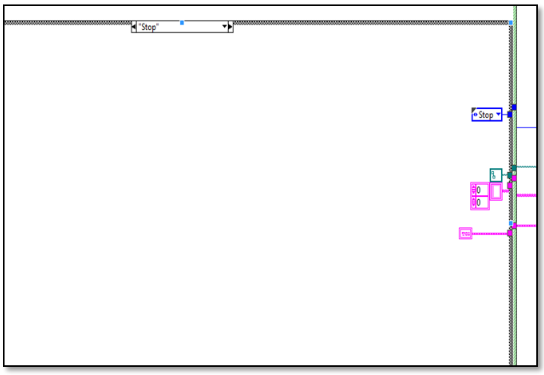


Fig. 11 Block diagram to stop the system.

4. RESULT AND DISCUSSION

This subtopic describes the result and analysis that carried out during the experimental work and crack recognition in RC beams. The RAC analysis method using AE data parameters that were employed for a detailed analysis of crack identification. That method is to develop a clustering system using NI LabVIEW to distinguish tensile cracks and shear cracks in RC beams.

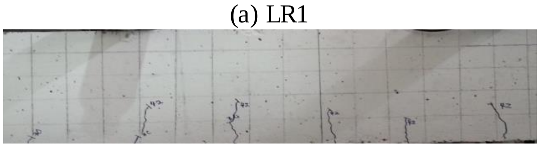
4.1 Crack Observation

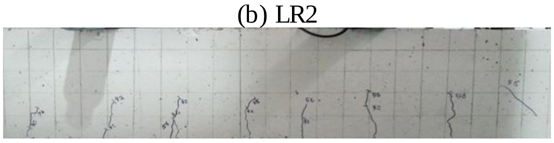
Figures 12 (a) - (f) present typical cracking propagation and fracture process of the concrete beams when the load ranges (LR) of LR1 to LR6 were applied for specimen 1. Then, the result analysis was proven using AE data parameters for the RA value which is a good indicator for real damage and crack classification in reinforced concrete. In this research, LR1 represents a loading of 0 to 20kN, while LR2 represents a loading of 21kN to 40kN. LR3 and LR4 represent loadings of 41kN to 60kN and 61kN to 80kN, respectively. Finally, LR5 and LR6 represent loadings of 81kN-100kN and 100kN until failure, respectively. All beams which were tested experienced shear failure but the initial flexural cracks can be clearly seen in Figures 12 (a) - (f).

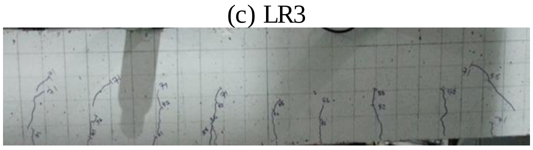
During the initial stage, micro-cracks appeared in the middle part of the beam when LR1 and LR2 were applied as shown in Figures 12 (a) - (b), respectively. This type of crack is known as flexural cracking. At this time, the tension steel began to bear the load which contributed to overall stiffness. Then, the loading was gradually increased to 41kN - 60kN and 61kN - 80kN which is above the service load level as shown in Figure 12 (c) and Figure 12 (d), respectively. The flexural cracks continued to grow and some diagonal cracks simultaneously formed between the support and the loading point as shown in Figure 12 (f). Throughout this point, the stirrup carried the shear load and contributed to the global stiffness of the beam. This type of crack is classified as mixed-mode cracking (flexural and shear cracks).

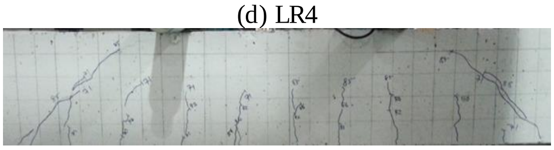
When the loading increased to the next level which is LR5 as presented in Figure 12 (e), flexural cracks grew quickly between the two-point loadings to form major cracks which spread to the compression zone. In addition, shear cracks started to form closely at both supports when the loading was increased to LR6 as shown in Figure 12(f). Both diagonal shears spread upwards toward the loading point while the flexural cracks showed no notable change. This period is known as diagonal crack development. Eventually, the flexural and shear cracks were wide open and connected when the loading reached the final point.


(a) LR1


(b) LR2


(c) LR3


(d) LR4


(e) LR5

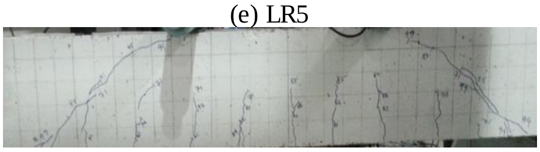

(f) LR6

Fig. 12 Detailed crack observation during laboratory work; (a) LR1, (b) LR2, (c) LR3, (d) LR4, (e) LR5 and (f) LR6.

4.2 RA Clustering (RAC) Method

The cluster analysis system is a statistical methodology to analyze AE parameters. The datasets of this study were obtained from acoustic emission signals recorded during flexural testing on reinforced concrete beams. The specimens consisted of normal reinforced concrete beams with a dimension of 150 mm x 250 mm x 1200 mm. The acoustic emission signals were acquired using four piezoelectric sensors (R6I-AST) in a linear arrangement as shown in Figure 3.

The clustering analysis of acoustic emission data parameters is important for distinguishing tensile cracks (Mode I) and shear cracks (Mode II). In this research, acoustic emission parameters which are a part of the datasets contain all signals for crack classification. This clustering system was developed using the cluster toolkit and functions found in the NI LabVIEW software. The front panel of the RA clustering system is shown in Figure 13 and the graph indicates the crack modes. From Figure 13, the cluster analysis consists of two colors, namely blue and red dots which represent tensile and shear cracks, respectively.

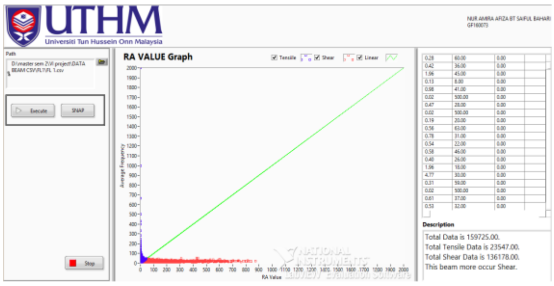


Fig. 13 Front panels of RA clustering for RC beams

The RA value graph in Figure 13 was generated after the clustering system was developed using the NI LabVIEW software. This clustering system was produced using AE data parameters, namely average frequency, rise time and amplitudes. The classification of cracks in this clustering system was made based on a formula created to divide the plotted data into two clusters. Cluster#1 which is y-coordinate plotted data < y-coordinate linear line to represent tensile failure and for cluster#2 y-coordinate plotted data > y-coordinated linear line to represent shear failure.

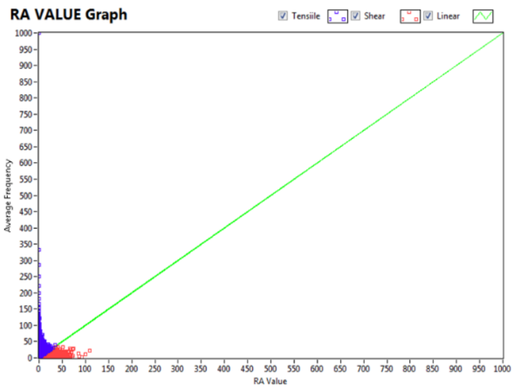
By using the RAC system, the analysis of the specimens is performed according to the load range (LR1-LR6) and the result is presented in Figure 14 (a - f). The results indicated a low level of tensile cracking at the initial stage for the load range 0kN - 20kN (LR1) as shown in Figure 14 (a). Tensile crack is nucleated during the early stage of the damage process and is followed by a shear movement [11]. The tensile cracking gradually increased as the loading increased and this eventually led to shear cracking. At this time, shear cracking was not too obvious as the tension bar reinforcement began to bear the load. This is was ascertained that the value of RA value increased slightly as shown in Figure 14 (b) compared to the RA value as shown in Figure 14 (c).

In Figure 14 (b), as the loading was increased to the load range 21kN - 40kN (LR2), the tensile cracks continued to grow gradually between two points of loading and reached the compression zone. When the loading increased to the next level which is LR3 (41 kN - 60 kN) as shown in Figure 14 (c), some diagonal cracks were formed between the support and loading simultaneously.

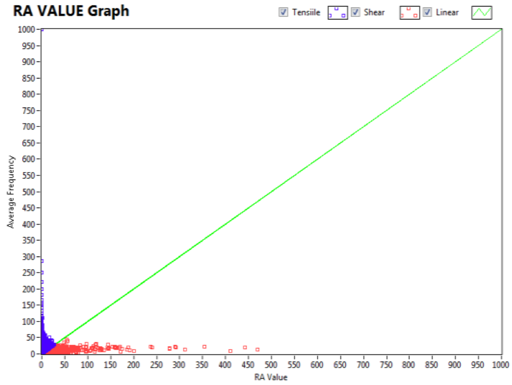
As shown in Figure 14 (d) and Figure 14 (e), the load was increased between 61kN - 80 kN (LR4) and 81 kN - 100kN (LR5), respectively. The diagonal shear cracks spread upward when fretting or sliding occurred on existing tensile cracks. The tensile cracks continued to grow along with some diagonal shear cracks. The shear movement developed more during LR4 and LR5 towards the end compared to LR1, LR2 and LR3.

In fact, the beam was reinforced with steel bar reinforcement and made-up the shear movement was restricted. It shows that the more tensile cracking occurred as clearly shown in Figure 14 (a – f), where the majority of located signals were tensile cracks accompanied by some shear movements as the damage increased. Throughout the process of crack propagation, tensile cracks were detected during the crack opening. After that, these conditions changed to sliding movements known as a shear movement.

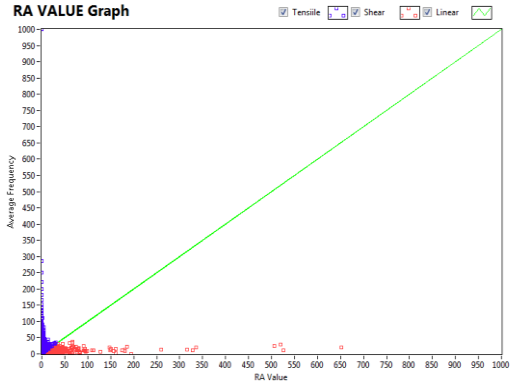
At the finale failure shown in Figure 14 (f), the tensile cracks could not go to the top but formed diagonal shears at the beam support which spread upward towards the approximate loading of 100kN until the specimen failed.



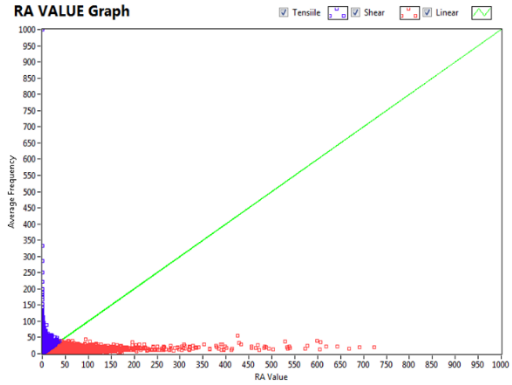
(a)



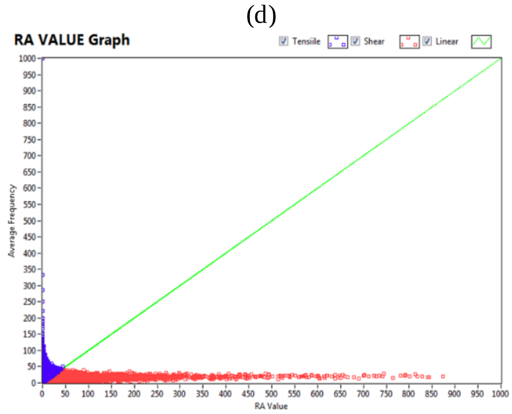
(b)



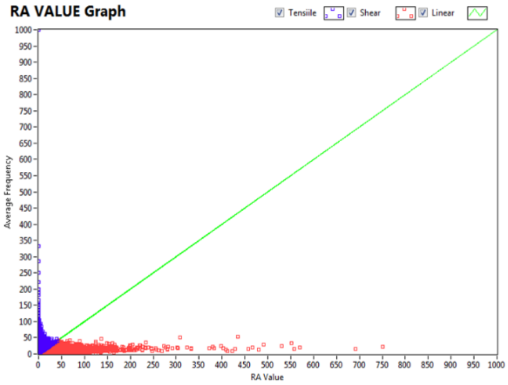
(c)



(d)



(e)



(f)

Fig. 14 RAC analysis for RC beam; (a) LR1, (b) LR2, (c) LR3, (d) LR4, (e) LR5 and (f) LR6.

The particular variations of RA value and average frequency were due to the loading sets as shown in Figure 14 (a – f) based on the load range. It can be concluded that RA value was lower and the average frequency showed the highest signal during the initial phase of loading, which is tensile cracks occurred. In contrast, when the RA value was higher compared to the average frequency, shear cracks occurred.

5. CONCLUSION

In the present study, acoustic emission energy was investigated to the determined type of cracking in the reinforced concrete beam. This study has successfully identified the crack classification using AE parameters such as amplitude, rise time and average frequency. RAC analysis was employed. The RAC analysis system has shown promise in the analysis of the types of cracking. The clustering system can be very helpful for engineers and researchers to analyze data during the monitoring of RC structures in laboratories or real-time monitoring using Acoustic Emission. Other than that, RAC shows the data visualization and provide users with the result that can simplify for further action. The ultimate achievement of RAC analysis system is to find the type of cracking from AE data set. In addition, RAC analyzing system was used to perform a cluster analysis of AE data and allow the system to generate the crack classification by using the AE data. In conclusion, the RAC analyzing method is successfully identified the crack classification using AE data parameter.

6. ACKNOWLEDGMENTS

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