

Identifying the Crack Nature Using b-Value Acoustic Emission Signal Analysis



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Abstract Concrete is an important constituent of structures. The strength performance of the concrete decrease due to several factors. Concrete suffers from deterioration at a later stage. Early and constant identification of concrete deterioration is necessary. Nowadays, non-destructive testing (NDT) is widely used especially on continuous real-time monitoring system with minimum labor involvement. It could also be used to discriminate the different types of damage occurring in reinforced concrete (RC) beam and real structure. In this research was monitored by using Acoustic Emission testing and it have several analysis such as RA-value, b-value, intensity signal analysis and historical index. To determine the acoustic emission signals for concrete structures and cracking identification this research using b-value analysis. b-value signals analysis contain useful information about damage mechanisms. A high b-value arises due to a large number of small AE hits, it representing new crack formation and slow crack growth, whereas a low b-value indicates faster or unstable crack growth accompanied by relatively high amplitude AE in large number. Reinforced concrete beams measuring of size 150 mm × 250 mm × 1500 mm were used during the acoustic emission test. A four-point load test was carried out on specimens until cracking occurred. The signals generated from the equipment were used for the analysis process, and the values are compared to define and summarise type of cracking and cracking processes.

Keywords Acoustic emission • Damage mechanisms • b-value

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1 Introduction

Concrete is one of the most widely used construction materials in the field of civil engineering discipline [1]. Concrete has high compressive strength, very strong chemical bonding and is durable for long-term structural conditions. Nowadays, concrete is used widely in the construction industry for building high rise buildings, dams, bridges, etc. Essentially, it is designed for to last for more than 50 years but due to aging, its quality and performance can be affected by cracking and other defects [2]. Basically, the damage can be seen during the formation of concrete. This early damage can affect the performance of concrete. It is important to monitor the condition of concrete during the early stages. The performance of concrete can be affected by concrete age [3]. The damage of concrete can generally occurred due to the corrosion of reinforced steel, freeze-thaw deterioration, chemical attacks, alkali reactivity, erosion of concrete, heat, restraint to volume change, overload, loss of support of other structures, seismic event and surface defects [4]. The damage of concrete could occur due to the ratio and quantity of materials used during the mixing process. These damages can affect the strength of concrete. A non-destructive test of concrete can be used to monitor the condition of the concrete [5].

A non-destructive test is a method to monitor the quality and condition of concrete and structures. This type of test is suitable for concrete testing without causing damage to concrete. Using this non-destructive test, many parameters of the concrete can be identified, such as density, modulus of elasticity and strength. The cracks and voids inside the concrete could be detected using powerful tools. There are a variety of non-destructive tests such as the rebound hammer test, pull out test, ultrasonic pulse velocity test, radioactive and penetration tests [6]. All of these methods are usually used in concrete monitoring in the construction industry. Acoustic emission is one of the non-destructive tests which is a really powerful tool that can be used for concrete monitoring [7].

Acoustic emission is a non-destructive test to monitor concrete damage in structural engineering. Acoustic emission is widely held to be a sensitive method which offers significant advantages in terms of early fault detection and diagnosis when compared to other monitoring methods [8]. It also can be used to analyse the different types of damage occurring in a composite material. An ideal system for concrete monitoring can show the harshness of damage and its location so that maintenance teams know where to look [9]. It is an early detection of defects. Acoustic emission is an ultrasonic wave radiating from an immediate release of strain energy when damage happens, for instance interface debonding, fibre breakage, and matrix cracking in composite materials [10, 11]. Useful information of the damage can be obtained from acoustic emission signal [12]. Therefore, this study mainly focuses on concrete monitoring using the acoustic emission method. The study are to determine the Acoustic Emission signal for concrete structure and to identify the type of cracking using Acoustic Emission signal analysis using b -value. The b -value analysis can consider all these factors and it could then be used as an alternative way to process and interpret data recorded during a local AE monitoring.

2 Experimental Procedure

Reinforced concrete beams measuring of size 150 mm × 250 mm × 1500 mm were used during the acoustic emission test. A four-point load test was carried out on specimens until cracking occurred. The specimens were test simultaneously in a four-point bending setup and the AE tests. In this study, normal concrete will be using cement, sand, coarse aggregate and tap water. Once the concrete has been mixed, it needs time to hardened and this process can take up a curing period of 7 or 28 days.

2.1 Analysis Method

There are many analysis methods that were used to analyse the acoustic emission of data obtained from tests such as Parametric Analysis (PA), RA Value, *b*-Value, Intensity Signal Analysis (ISA) and a brand new method that is called Intensity Absolute Energy Analysis (IEA) [13, 14]. Parameter Analysis (PA) is a really dominant method that can be used to analyse materials [15]. It also known as a classic method for the analysis process due to the usage of the method for the last few decades. That method were used to identify the array of waves for parameters. The statistical value and combination among the parameters have been studied and proven for the fracture scale and degree of damage in structures. The measurable value and a combo among the parameters have been considered and demonstrated for the crack scale and level of damage system in the structures. There are some examples that have been applied together in previous studies such as the Kaiser effect and the Felicity effect. Every method has its own characteristics in terms of the acoustic emission signal to be processed. The *b*-value can be defined as the slope of the log-linear of frequency magnitude distribution of the acoustic emission [16]. It is also called the statistical method.

$$\log_{10}N = a - bM_L \quad (1)$$

N is referred to as the incremental frequency while *M_L* is referred to as the Richter magnitude. The *a* is an empirical constant while the *b* value is called *b*-value. The value of *b* can be used to identify the type of cracks. A high *b*-value arises due to a large number of small AE hits, it representing new crack formation and slow crack growth, whereas a low *b*-value indicates faster or unstable crack growth accompanied by relatively high amplitude AE in large number. At the end, the values are compared to define and summarise the type of cracking and cracking processes as shown in Table 1.

Table 1 Quantitative result analysis

Value	Description
>1.7	Dominant of micro-cracks
1.2 > value < 1.7	Distributed cracking uniform pattern
<1.2	Dominant of macro-cracks

Source Angeles [17]

3 Methodology

Acoustic emission was used to monitor concrete condition after the curing process. The equipment possessed sensors that can be attached to the concrete specimens. The attachment of sensors to the concrete specimens has to be done on a flat surface. All the sensors connected to the concrete must also be connected to the acoustic emission detection instruments and a computer as shown in Fig. 1. All the data appeared on the computer to enable further analysis.

3.1 Test Setup

The beam is painted on the each side in white to make it easy to identify the crack patterns before the test is conducted. After that, the beam surface is smoothed for AE sensor installation. This is done to ensure proper attachment between the AE sensor and the concrete surface. The AEWin software must be set up after the installation of the AE sensors and before testing. After all the setup procedures are completed, a load can be applied to the beam.

Figure 2 shows the load test on the beam to obtain the maximum load that can withstand by the beam. The value is 127 kN, which is the maximum load of use for the cyclic load during the acoustic emission test. The cyclic load used during the acoustic emission test and every load set has a 3-min loading hold.

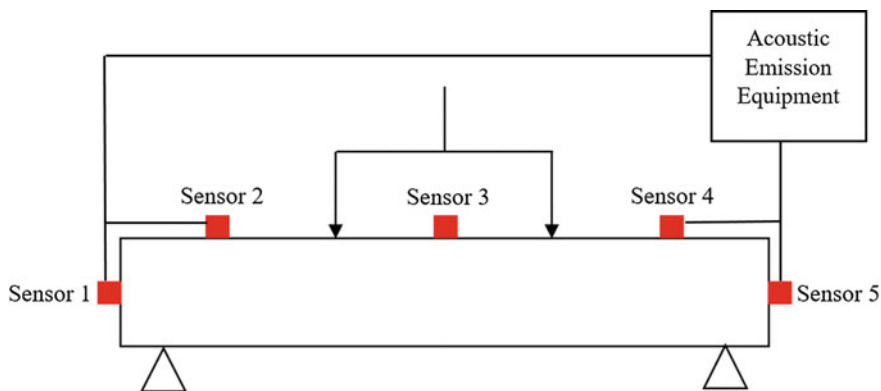


Fig. 1 Set up of the sensors to the acoustic emission detection instrument

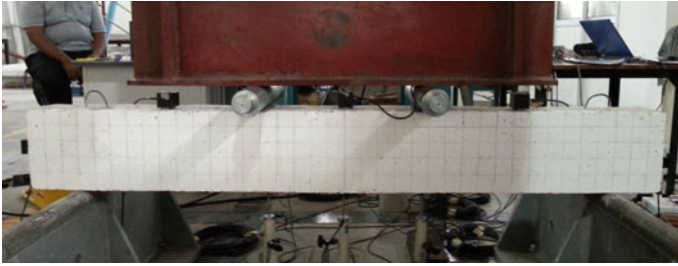


Fig. 2 Testing observation in the laboratory work

4 Result and Discussion

The b -value analysis method was used in this study to evaluate all the AE data obtained from the fracturing process of concrete beams. The incremental frequency and amplitude value were the parameters used in the evaluation of this analysis method. The amplitude data was documented by the Acoustic Emission μ -SAMOS system. The methods of analysis was verified to be suitable for the development of cracks within the concrete material and structure. The b -value method displayed progress of the fracturing process from micro-cracking to macro-cracking. All these methods were analysed according to the AE event data recorded.

4.1 Real Crack Observation

This subchapter covers the development of the cracking and breaking process of the concrete beams during the test. All the beams usually display the same cracking pattern. The micro cracks can be seen during the initial stage of the test at the middle part of the beam as shown in Fig. 3a, b. This crack type is called flexural cracking. At the same time, steel experiences tension from the load exerted during the test.

The loading increased above the service load level from around 60–71 kN. Flexural cracks propagated and simultaneously several diagonal cracks were formed between the support and the loading point as seen in Fig. 3c, d. At the same time, the link experienced shear load and influenced the stiffness of the beam. This type of cracking is called mixed mode cracking as it is a combination of flexural and shear cracking.

The loading increased to the next load level to around 85 kN. The flexural cracks developed rapidly between two-point loading to produce major cracks which later spread to the compression area. Besides, the shear cracks started to occur near both supports as shown in Fig. 3e.

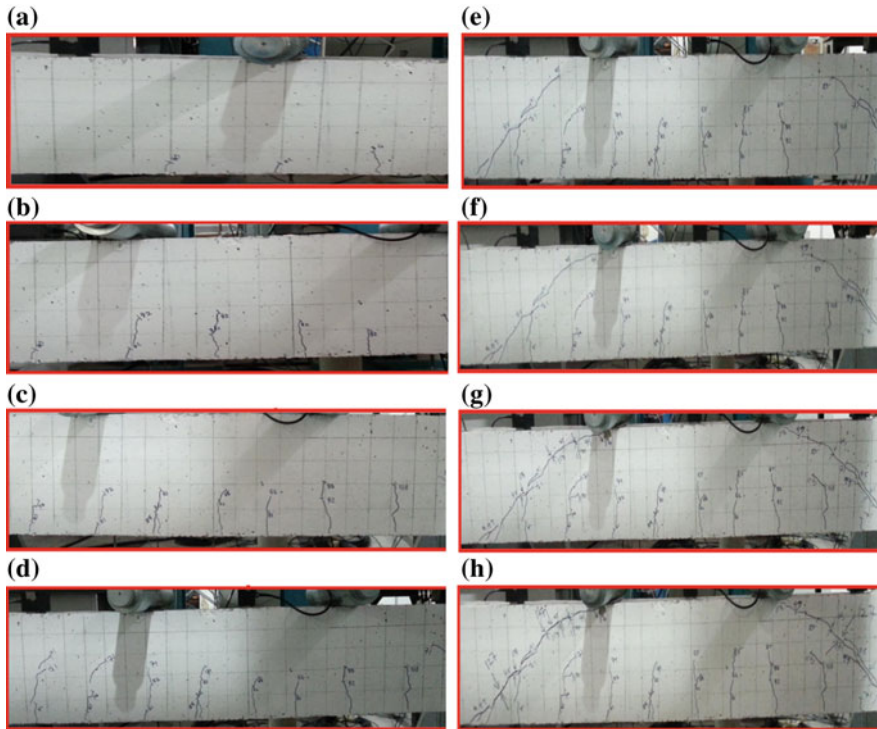


Fig. 3 Crack observation; **a** Load 1; **b** Load 2; **c** Load 3; **d** Load 4; **e** Load 5; **f** Load 6; **g** Load 7; **h** Load 8

Next, in Fig. 3f, g show the loading increased to approximately 100–120 kN and both diagonal shears moved vertically to the loading point. Meanwhile, the flexure cracks remain the same as the loads before. During this period, it is known as diagonal crack development as shown in Fig. 3h. In the end, flexural and shear cracks developed extensively even after the loading achieved the final point.

4.2 *b*-Value Evaluation

From the graph on amplitude versus time on each load set for the cyclic load test (CLT) method, the highest amplitude can be seen at the beginning from the service load level (LS4). The highest amplitude ranges between 95 and 100 dB and the value of the highest amplitude increased for the next service load. This can be observed in the graph from LS5 to LS8 as shown in Fig. 4. This increment in amplitude shows the process of the fracture. The AE data can be used to identify the type of cracking.

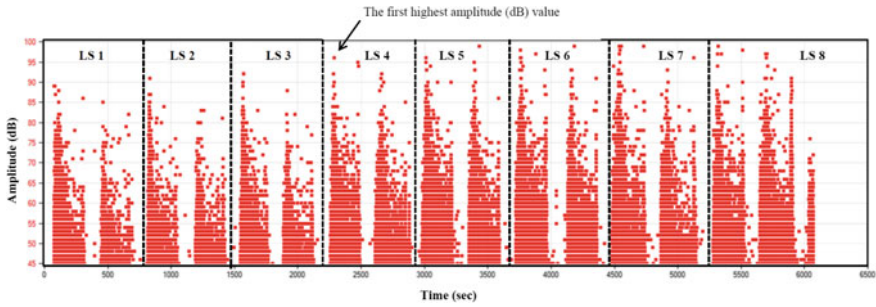


Fig. 4 Amplitude versus time graph

Figure 5 shows the graph x-axis and y-axis are the amplitude versus X position, respectively. Three stages of distributed amplitude and events occurring during the acoustic emission test on three separate graphs. The AE data analysis showed where the cracks were located in the reinforced concrete beam. This section explores the utilisation of AE data parameters to identify and establish the damage level classification at critical areas of the reinforced concrete beam based on the AE events. Along the beam, the events occurred mostly at the support to the middle of the beam. The red dot on the graph showed high events occurring on the beam. The dots plotted represent the cracks occurring at a certain position.

The data recorded by the AE software was processed and analysed using Microsoft Excel as a procedure to measure and complete the *b*-value analysis. The total number of the events was divided according to range and each range consisted of five amplitudes. The lowest was 45 whereas the highest was 99. The groups of amplitudes were converted into *b*-values which were then plotted on the graph formed between log frequency-magnitude against *b*-value. The best fit line was constructed for each graph to obtain the gradient and equation of the line. The analysis process was divided into five parts according to the five sensors. The *b*-value was calculated based on a rearranged formula in Eq. (2).

$$b\text{-value} = \frac{\log N - N}{Amp} \tag{2}$$

where

N Incremental frequency

Amp Amplitude average.

Based on result of *b*-value from Table 2, the condition of concrete cracks during the test can be identified. A *b*-value higher than 1.7 is considered as a microcrack while a *b*-value lower than 1.2 is considered as a macrocrack. Thus, the condition of cracks can be identified based on the *b*-values. Table 2 shows that at Channel 2, there are more macrocrack events occurring compared to other channels. Channel 4 displayed the second highest number of macrocrack events. Channel 2 and Channel



Fig. 5 Amplitude versus position versus events

4 were located above the support of the beam. From the test and b -value data, most of the cracks occurred at both supports of the beam before spreading to other parts. Figure 6 shown the fracture process during the test with the b -value label.

Based on all five graph in Fig. 7, the gradient of the best fit line between cumulative frequency against b -value seems to be channel 2. This is because it has the lowest gradient value of 4.3675 compared to other channels. Channel 4 has the second highest gradient value of 11.312. A low gradient shows that there are macro cracks occurring near the sensor channels. Usually, all the cracks of the beam occur from the support and the centre of the specimen before they spread to other parts. The locations of the sensors for channel 2 and channel 4 are right above the beam support. From this discussion, it is evident that cracks occur at the support area of the beam.

All the b -value data was plotted against the average amplitude of each range. The graphs were plotted separately for each channel. Based on Fig. 8, channel 2 has a low b -value because of macro cracks occurring g at that section, followed by channel 4. This is because both channels were located above the support area. The three other channels experienced less macro cracks which resulted in higher b -values.

Table 2 *b*-value for each channels

Amplitude	Channel 1	Channel 2	Channel 3	Channel 4	Channel 5
45–49	2.00	2.00	2.00	2.00	2.00
50–54	1.81	1.81	1.81	1.81	1.81
55–59	1.66	1.67	1.66	1.66	1.66
60–64	1.53	1.57	1.53	1.53	1.53
65–69	1.42	0.69	1.42	1.42	1.42
70–74	1.32	0.38	1.32	1.32	1.32
75–79	1.24	0.06	1.24	1.24	1.24
80–84	1.17	0.02	1.17	1.17	1.17
85–89	1.12	0.00	1.11	1.13	1.11
90–94	0.67	0.00	1.06	0.41	1.07
95–99	0.47	0.00	1.00	0.27	0.53

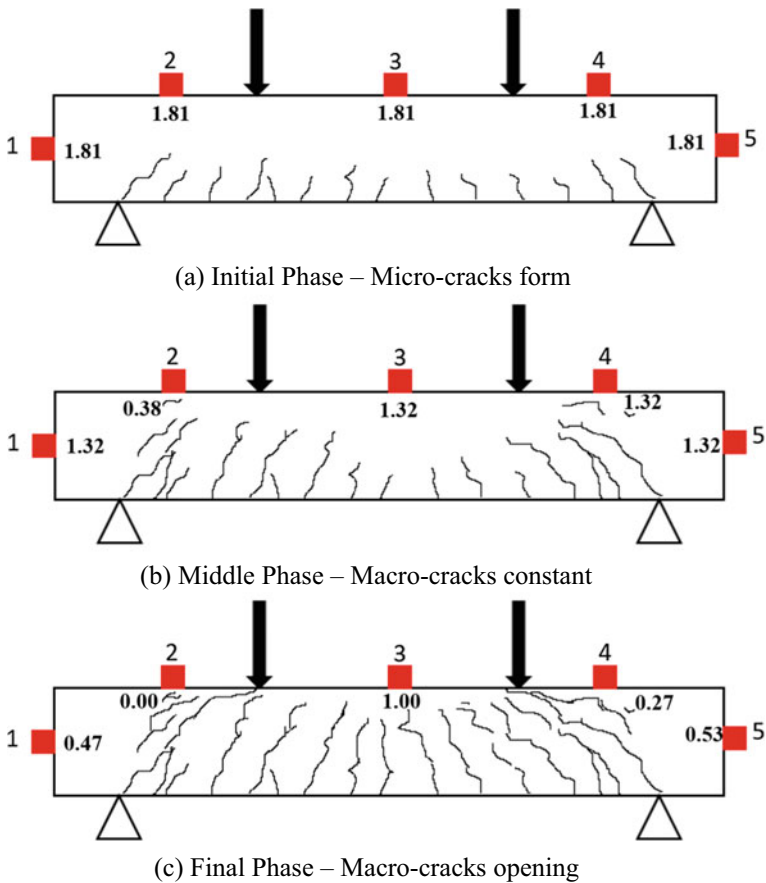


Fig. 6 Fracture process during the test with the *b*-value label

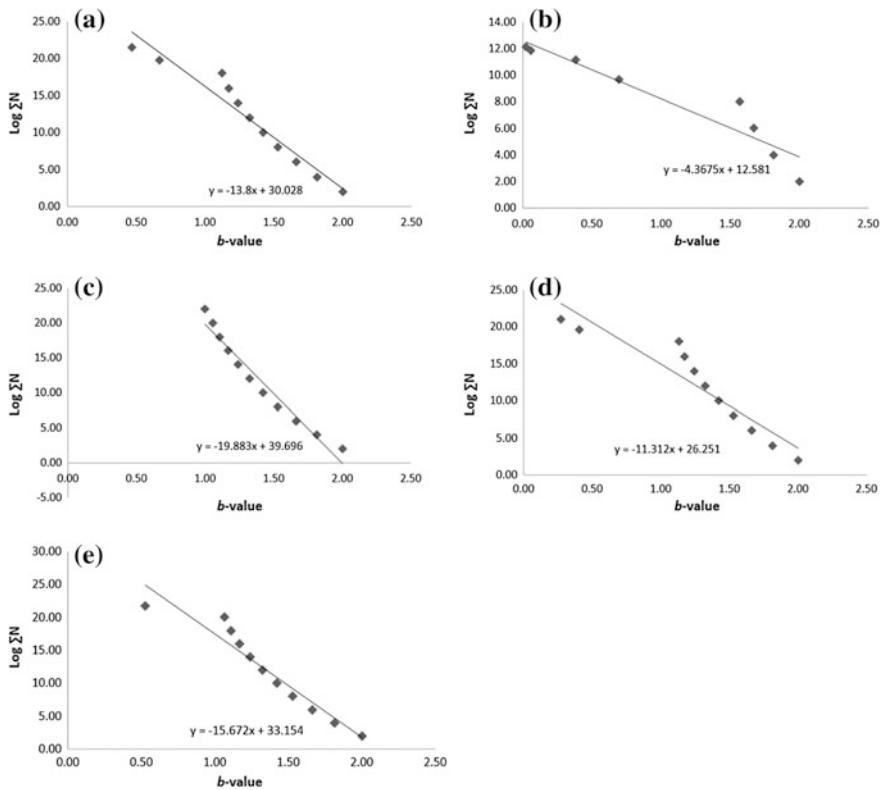


Fig. 7 *b*-value analysis for each channel; a Ch1; b Ch2; c Ch3; d Ch4; e Ch5

5 Conclusion and Recommendation

Based on the results of the acoustic emission test in the laboratory and analysis of the data generated, the following conclusions can be drawn:

- i. The *b*-value method was the method used to analyse data generated from the acoustic emission test. All the data generated from the software was converted into *b*-values to determine the crack type and the location where the cracks occurred. A *b*-value higher than 1.7 represents the presence of micro cracks while a *b*-value lower than 1.2 represents the presence of macro cracks. The results show that sensors at Channel 2 and Channel 4 have lower values compared to the other three channels. This means that macro cracks occurred from the support of the beam before spreading to other parts. More cracks occur at both two channels.
- ii. The best fit line graph of cumulative frequency against *b*-value was plotted for each channel to compare gradients. A low gradient value means that macro-cracks occurred near the sensors of that channel. This study showed that channel

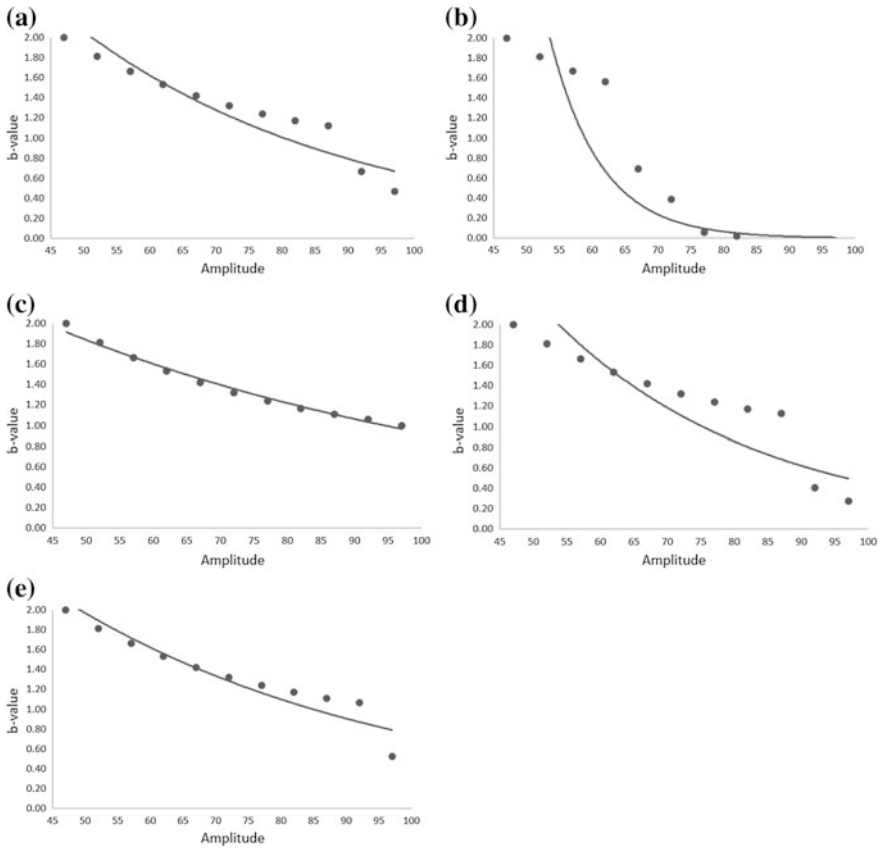


Fig. 8 *b*-value versus amplitude; **a** Ch1; **b** Ch2; **c** Ch3; **d** Ch4; **e** Ch5

2 has the lowest gradient value while channel 4 has the second lowest gradient value. Both sensor channels were located vertically along the beam supports. Channel 2 and channel 4 have gradient values of 4.3675 and 11.312, respectively. This means that cracks initially occur from the support area.

Moreover, following recommendations have been made for future studies:

- i. Acoustic emission sensors can be attached to specimens so that the location of concrete cracks and the types of concrete cracks can be identified more accurately.
- ii. Support location can be changed to observe other crack patterns.
- iii. Amplitude range for *b*-value can be reduced to less than five of not calculated in range.

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