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Quality evaluation of concrete aggregate by weibull-distribution analysis of AE

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ABSTRACT: In order to develop a simple quality evaluation of recycled aggregate, an aggregate loading test is conducted. Simulating damaged recycled aggregate, natural aggregate and artificial aggregate are mixed as control samples and employed in the aggregate loading test. As the crushing values of aggregate increased along with the compressive load, it is found that the increase in the crushing values depends on the quality of aggregate. The crushing value and the acoustic emission (AE) in the compressive tests were analyzed by the Weibull distribution. The quality of samples was evaluated by m values. As a result, the m values of the crushing values and the acoustic emission(AE) hits were well correlated with actual quality of samples.

1 INTORODUCTION

A large amount of old structures are so increasing that they need to be renewed or repaired. As a result , a large number of waste concrete are generated. So, it is desirable to collect recycled aggregate from waste concrete. Recently, renewal recycles technologies for concrete have been developed in Japan. These are a heating grinding method and grinding method. They can collect high-quality recycled aggregate of class H of JIS[1]. In most cases, quality of recycled aggregate is evaluated by a density test, an absorption test and a sieve test etc. Because, the quality of recycled aggregate increases with increasing the treating time, a technique to determine the proper treating time is necessary. As aggregate is crashed later, the amount of powder particles also increases. It is not easy to conduct the density test, the absorption test and the sieve test under treating. So, a simple quality evaluation method of recycled aggregate is desirable. Although, it is necessary to physically evaluate recycled aggregate by the density test, the absorption test and the sieve test, the cost and time could reduce, if the quality of recycled aggregate is evaluated by a simple test. Consequently, the aggregate loading test in TS A 0006[2] is selected. The the mechanical property of recycled aggregate is estimated by a crushing value. Previously, the aggregate-loading test was applied to recycled aggregate, which was collected by a pulsed power discharge[3]. The maximum load was set to 100kN, and the crushing value was calculated after each 20kN loaded. The crushing value was analyzed by Weibull distribution [4]. As a result, it is found the transition of the crushing value is clearly related to the quality of recycled aggregate. However, it was found that the maximum load of 100kN was dissatisfied to evaluate the mechanical strength of recycle aggregate. According to the aggregate crushing test in the British standard (BS-812) [5], the maximum load of 400kN is prescribed. Accordingly, this research examines the validity of simple quality evaluation of concrete aggregate by the aggregate loading test with the maximum load of 400kN. The crashing value is calculated after each 80kN was loaded. Natural aggregate and artificial aggregate are applied to examine the validity of simple quality evaluation. The crushing value is analyzed by the Weibull distribution. In addition, the acoustic emission (AE) generated under compressive load is also detected. Then, AE activity is analyzed by the Weibull distribution.

2 AGGREGATE LOADING TEST

Figure 1 shows a sketch of the aggregate-loading test. Sizes of the apparatus are described in Table 1.

The crushing value was calculated by Equation 1 after sieving with 2.5mm sieve at each 80kN load increment.

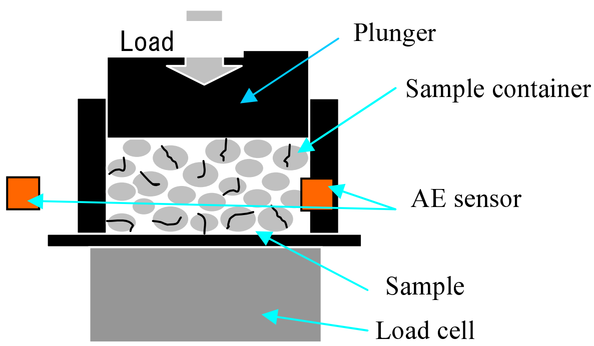

Figure 1. Sketch of aggregate loading test.

Table 1. Apparatus.

	Size
Sample container	Inside diameter 154mm Inside higher 140mm
Plunger	diameter 152mm

$$Crushing \cdot value = \frac{m^1}{m^0} \times 100 \quad (1)$$

m_1: Mass of sample through the 2.5 mm sieve(g)
m_0: Mass of all sample (g)

AE hits were detected at the aggregate loading test. In the test two AE sensors those were installed in the sample container. The threshold for AE detection was set to the 70dB. AE activity could result from the sources whose aggregates fret mutually and the aggregates are crushed. The crushing values are calculated from the both measure events of AE hits and the crushing values.

3 WEIBULL DISTRIBUTION

The Weibull distribution is a frequency function that is applied to describe the fracture of a material. The fracture phenomenon of the material is assumed to result from the weakest point in the material, then fracture proceeds. In the case of the aggregate-loading test, fracture starts from the weakest aggregate when aggregate are loaded. The aggregates are consecutively broken with the increase in the load. Failure of aggregate happens at low load when a weak aggregate exist. In the other case, aggregate is not broken until a high load because weak aggregate is not contained. A fracture probability of aggregate could be analyzed by the Weibull distribution. The Weibull distribution λ(x) is given in the following from

$$F(x) = 1 - \exp\left(-\frac{x^m}{\alpha}\right) \quad (2)$$

where f(x) is the density function, F(x) is the distribution function, m is the shape population parameter, and α is the scale parameter.F(x) and f(x) are calculated from the hazard function, as follows;

$$F(x) = 1 - \exp\left(-\frac{x^m}{\alpha}\right) \quad (3)$$

$$f(x) = \frac{mx^{m-1}}{\alpha}\exp\left(-\frac{x^m}{\alpha}\right) \quad (4)$$

The logarithm is taken twice in both sides of Equation 2.

$$\log\left[\log\left\{\frac{1}{(1-F(x))}\right\}\right] = m\log x - \log\alpha \quad (5)$$

Setting to as

$$X = \log x \quad (6)$$

$$Y = \log\left[\log\left\{\frac{1}{(1-F(x))}\right\}\right] \quad (7)$$

we have,

$$X = mx - \alpha \quad (8)$$

The Weibull distribution can evaluate the quality of material by m value in Equation 8. When m value is smaller than 1.0, it is referred to as an initial failure-type. A happening failure-type is assigned when m value=1. It is called a wear failure-type when m value>1. An increase in m value shows an increase in the quality of material. The quality of aggregate is evaluated as high quality, when m value increases. One example of the Weibll distribution is shown in Figure 2.[6)]

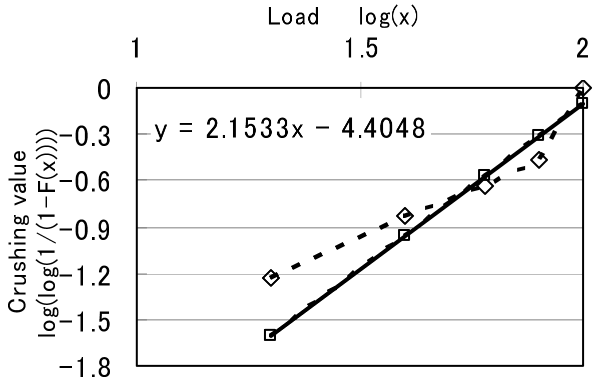

Figure 2. Weibull distribution.

The x axis corresponds to the load assigned in Figure 6, as the maximum load is set to be 100%. The y axis shows the crushing value, as the maximum crushing value is set to be 100%. Here, the crushing value is assigned in Equation 7. The cumulative failure rate is also plotted by a broken line. The approximation accumulation failure rate (solid line) is plotted by a nonlinear minimum mean square method. The gradient of the approximation accumulation failure rate (solid line) corresponds to m value.

4 AGGREGATE LOADING TEST USING BY NATURAL AGGREGATE AND ARTIFICIAL CONCRETE AGGREGATE

4.1 *Sample of aggregate*

Natural aggregate and artificial aggregate[7)] are employed in the aggregate loading test. A rock type of natural aggregate is gabbro. These aggregates were mixed as an alternative of the recycled aggregate. Mix proportion of natural aggregate and artificial light-weight aggregate are controlled as five cases, as shown to Table 2. In Table 2, AL indicates the artificial light-weight aggregate, and the mixing ratio follows as percentage.

Table 2. Mixing rate of sample.

Sample	Mixing rate	
	Natural aggregate	Artificial light-weight aggregate
AL-100	0	100
AL-75	25	75
AL-50	50	50
AL-25	75	25
AL-0	100	0

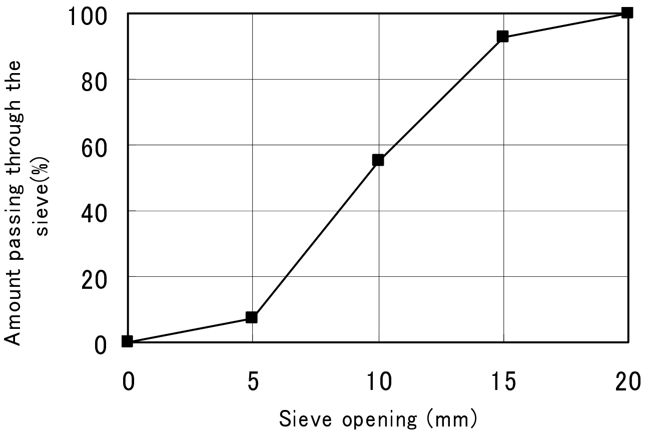

Figure 3. aregate gradation curve.

Figure 3 shows the gradation curve of all aggregates in Table 2. To make the samples, controlling the particles sizes are controlled with the same gradation curve as shown in the figure. The size of the maximum aggregate is 15mm.

4.2 *Physical property of natural aggregate and artificial light-weight aggregate*

The artificial light-weight aggregate is manufactured from shale. Table 3 shows physical properties of these aggregates.

Table 3. Physical property of natural aggregate and artificial light-weight aggregate.

		Artificial light-weight aggregate	Natural aggregate
Absolutely dry density (g/cm^3)		1.22	3.04
Absorption ratio (%)	24hour	12.68	0.49
	Sell-in	24 ~ 34*	—
Specific weight (kg/l)		0.77 ~ 0.82*	1.77
Solid volume percentage (%)		63 ~ 65*	58.4

*Catalog specs

4.3 *The density and absorption test of samples*

Table 4 shows results of the density and the absorption tests of samples.

Table 3. Result of density and absorption test.

Sample	Crushing value (%)				
	80kN	160kN	240kN	320kN	400kN
AL - 100	5.8	15.8	24.3	30.7	35.6
AL - 75	4.5	13.9	19.7	25.6	31.1
AL - 50	2.7	8.5	14.2	21	23.5
AL - 25	1.6	3.7	10.4	13.5	15.7
AL - 0	0.5	1.9	4.1	6.9	10.1

Since, AL-100 is only made of the artificial light-weight aggregate, the density is the lowest and the absorption is highest, while AL-0 has the highest density and the lowest absorption ratio.

4.4 *Aggregate loading test*

In the aggregate loading test, load levels were set to 80kN, 160kN, 240kN, 320kN, and 400kN. The crushing value was calculated at each load. Table 4 shows results.

Table 4. Crushing value of each sample.

Sample	Absolutely dry density (g/cm^3)	Absorption ratio (%)
AL - 100	1.22	12.68
AL - 75	1.42	8.37
AL - 50	1.68	7.31
AL - 25	2.35	3.34
AL - 0	3.04	0.49

The crushing value increases with the increase in the load. The crushing value has increases with the an increase in the ratio of the artificial light-weight aggregate. The crushing value can evaluate dynamic strength of the sample. A load-bearing capacity of the sample is high when the crushing value is small. It was thought that the decrease in dynamic strength showed the decrease in quality of samples. Results of the crushing values are in agreement with these of the density and the absorption tests. Thus, as the aggregate quality usually evaluated from the density and the absorption ratio, the crushing value is an effective parameter to evaluate the quality aggregate. The increasing rate of the crushing value with the increase in the load could result from the quality of sample.

4.4 *Weibll distribution analysis of crushing value*

The crushing value was analyzed by the Weibull distribution, and m value was calculated. The change of m value was examined according to the change in the density and the absorption ratio of each sample. Figure 4 shows the Weibull distribution of the crushing value.

The x axis is set to be 100% when the load is 400kN. The crushing value is assumed to be 100% at 400kN, and each crushing value is normalized by Equation 7. The cumulative failure rate (broken line) is plotted as the actual measurement value. The approximation accumulation failure rate (solid line) is approximated as the Weibull distribution by the nonlinear least-squares method. The gradient the determined in graphs corresponds to m value. The m values determines are all larger the 1.0. These are summarized in Figure 5.

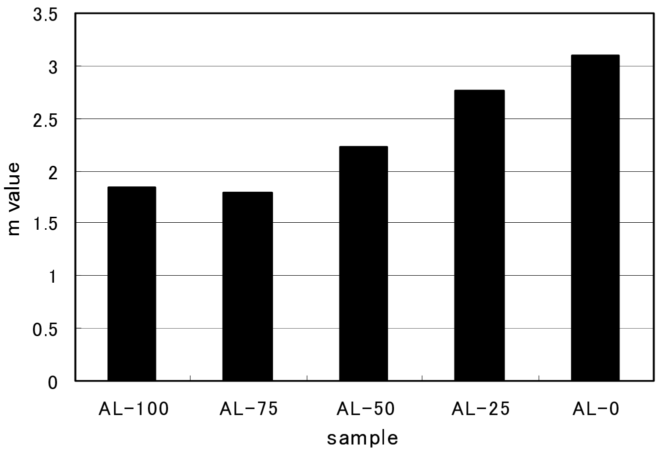

Figure 5. The m value of each sample.

The m value increases when the sample with low mixing rate for the artificial light-weight aggregate. Thus, the quality of aggregate is evaluated as high quality, when m value increases. The quality of sample increases with the decrease in the mixing rate for the artificial light-weight aggregate. It is shown by results of the density test and the absorption test. Thus, the increase in m value could be associated with the increase of the quality of the sample. The m values of AL-75 and AL-100 in Figure 5 draw an attention. These m values are smaller than other m values of samples. When the m value is small, there are a lot of failures in aggregates. The quality of AL-75 is higher than that of AL-100, which is clearly observed in result of the density and the absorption tests. The m value of AL-100 could become smaller than the m value of AL-75, because the mixing rate of artificial light-weight aggregate is higher as the load-bearing capacity of the artificial light-weight aggregate is lower than that of the natural aggregate. A lot of fractures could occur in the artificial light-weight aggregate at low load level. So, the m value reached the almost same value. On the other hand, the crushing value of 400kN of these samples exceeded 30%. In the BS, the sample for the crushing value to exceed 30% was regulated as a weak sample, because an accurate the m value might not be obtained.

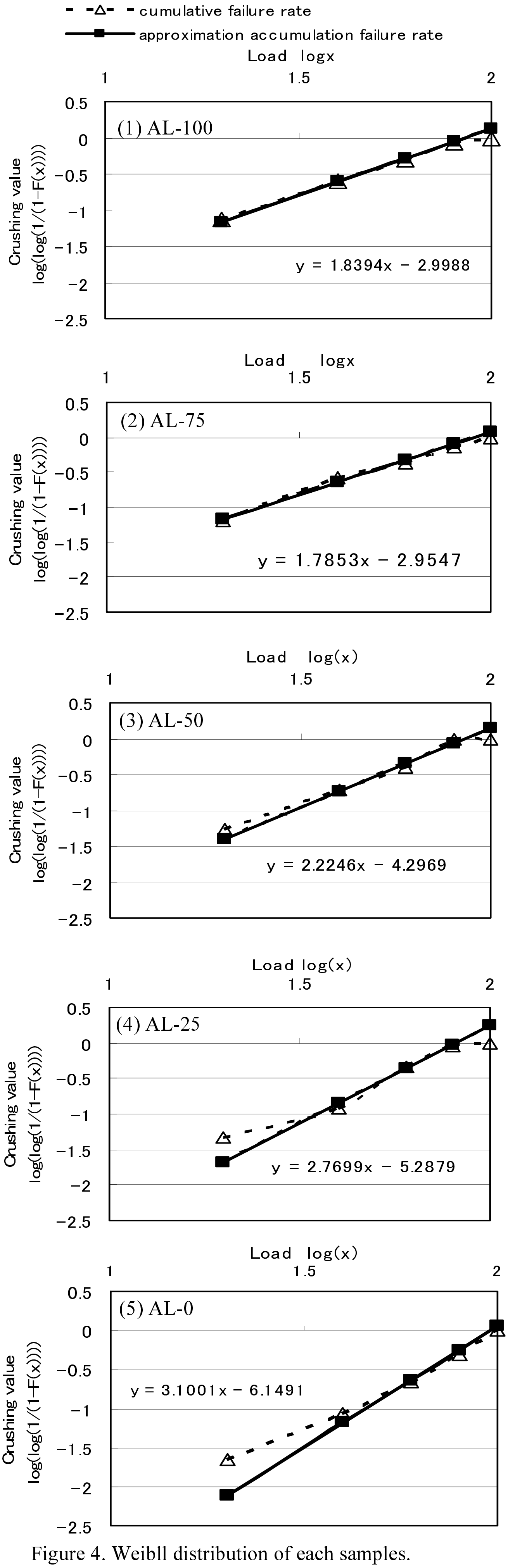

Figure 4. Weibll distribution of each samples.

4.5 *Weibll distribution analysis of acoustic emission*

The parameter of the breakdown factor was assumed to the load of 400kN when detected AE hits were applied to the Weibull distribution. The relation between the load up to 400kN and detected AE hits was approximated by a straight-line in each sample by using the nonlinear least-squares method. The m value of each sample was calculated, and a correlation between the m value and the quality of sample was examined. The load from 0kN to 400kN was divided of each 40kN to analyze the generation behavior of AE. The number of accumulation AE hits is shown in Figure 6. The number of AE hits in Figure 6 is the average of two AE sensors. These AE hits were analyzed by the Weibull distribution. Figure 7 shows the Weibull distribution of each sample. The x axis is set to be 100% when the load is 400kN. The AE hits are accumulated as assumed to be 100% at 400kN, and each crushing value is normalized by Equation 7. The cumulative failure rate (broken line) is plotted as the actual measurement value. The approximation accumulation failure rate (solid line) is approximated as the Weibull distribution by the nonlinear least-square method. The gradient the determined in graphs is approximation accumulation failure rate corresponds to m value. The m values are all larger the 1.0. Those m values are summarized in Figure 8.

AE activity at low load could result from aggregate fretting, and then aggregates crushing. In the Figure 6, a lot of AE hits are observed in low load levels when the mixing rate of the artificial lightweight aggregate of the sample is high. The number of detected AE hits of-AL75 is more than that of AL-100. The mixing rates of the artificial lightweight aggregate are high for these samples. Thus, a lot of failures might occur in the artificial lightweight aggregate. The m value of AL-0 is largest in Figure 8. There is a good correlation between the m values of that and the quality of the samples. Interestingly, the m value of AL-100 is larger than that of AL-75. Because, mixing rates of the artificial lightweight aggregate are high in these samples, there exist a lot of weak particles in the samples. Thus, the amount of the aggregates crushed by the load is large. As can be found, the crushing values of these samples exceed 30%. The aggregate could fret mutually at low load by a low load level, and many AE hits were detected. As a result, the m values of these samples became large. This is a reason why the m value of AL-100 is higher than that of AL-75. In the case of AE analysis, the early stage of aggregate fretting could load to a reverse trend between AL-100 and AL75.

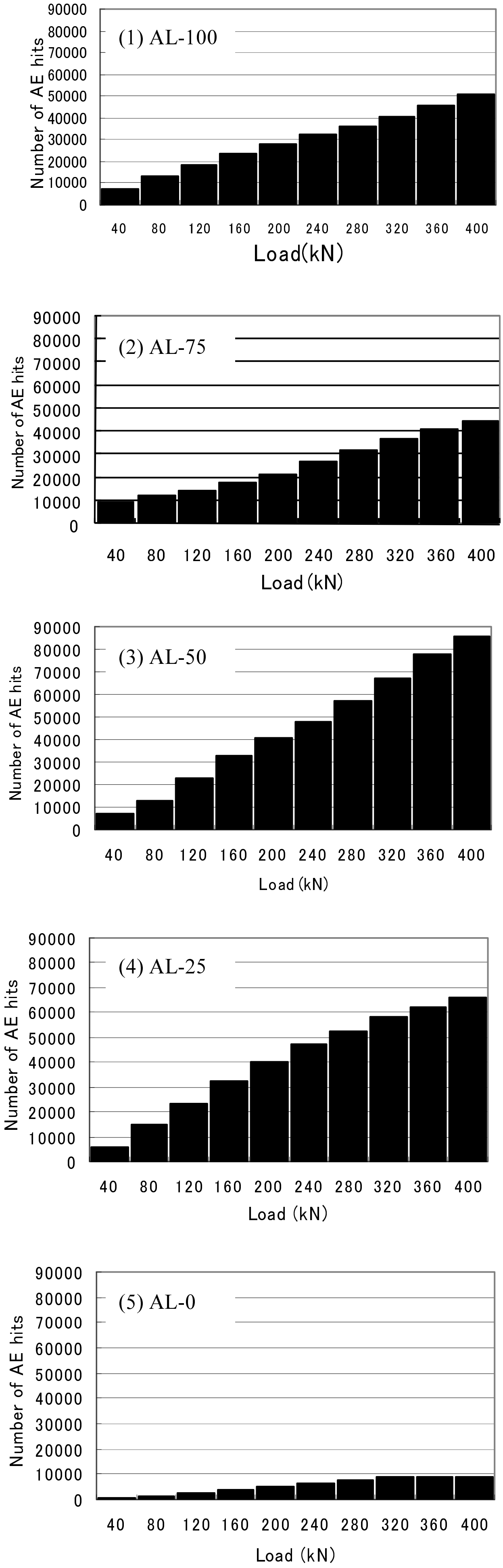

Figure 6. The number of AE hits of each sample.

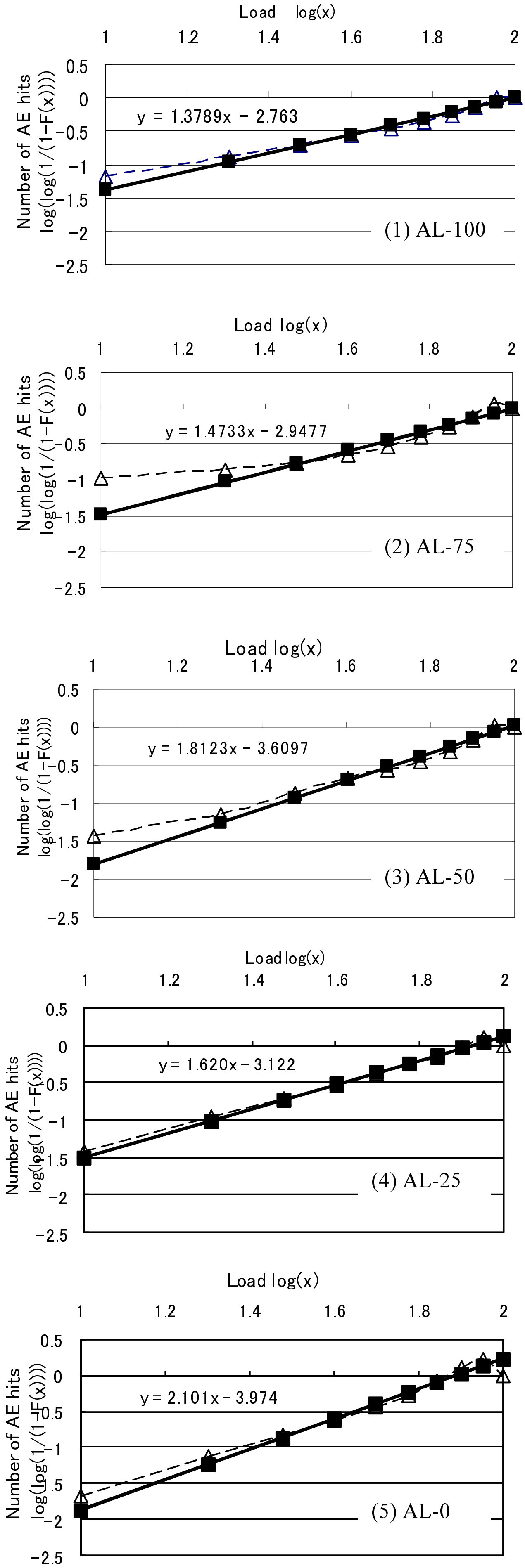

Figure 7. Webull distribution of AE.

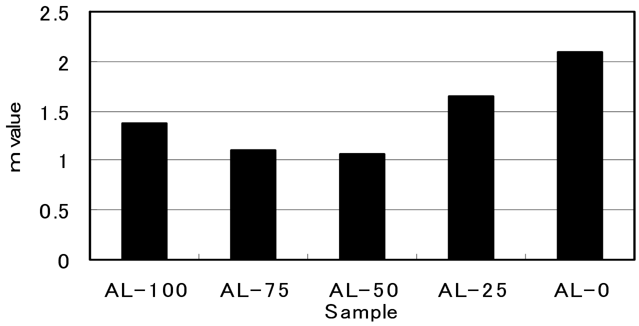

Figure 8. The m value of each sample.

5 CONCLUTIONS

The aggregate-loading tests were conducted to propose the simple quality evaluate method of recycle aggregate. The samples that mixed natural aggregate with artificial-light weight aggregate were employed. The crushing value was analyzed by the Weibull distribution. In addition, AE hits generated under compressive load was detected. AE activity was also analyzed by theWeibull distribution.The crushing value was increased as the mixing rate of the artificial light-weight aggregate increased in each sample. The quality of sample was decreased by increasing the mixing rate of the artificial light-weight aggregate. So, there was a good correlation between the quality of sample and the crushing value. The difference of the increasing rate of the crushing value with the increase in the load relate to the quality of sample. The m value of crushing value increased as the mixing rate of the artificial light-weight aggregate decreased. The increase of the quality of the sample was confirmed by the m value of the crushing value. On the other hand, the m value of AE activity was increased as the mixing rate of the artificial light-weight aggregate decreased. The increase of the quality of the sample was also confirmed by the m value of the AE. It is concluded that the simple quality evaluation of aggregate including weak gravels by the Weibull distribution is very promising.

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