A New Method for the Assessment of Deteriorated Paper Documents

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A New Method for the Assessment of Deteriorated Paper Documents

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To assess the ageing characteristics of books and paper documents, a new method using acoustic emission (AE) monitoring was developed. AE monitoring is a non-destructive or a limited-destructive technique that monitors high frequency sounds emitted by a material when it is under stress to determine the onset and progression of small-scale damage. By measuring the time from the moment the AE sensor contacts the paper surface to the moment the maximum AE ring-down counts are detected, the extent of deterioration of the paper can be evaluated. To investigate the applicability of AE monitoring for the assessment of damaged paper, naturally aged commercial wood-free papers and paper from old books were used as test samples. We tried to determine whether AE monitoring could effectively discriminate between naturally aged papers in good and poor condition. The time taken to reach the maximum AE ring-down count in acidic papers was considerably shorter than that taken in acid-free papers. The time to reach the maximum AE ring-down count in samples of book paper in poor condition was considerably shorter than in samples taken from well-preserved books. The time to the maximum AE ring-down count was correlated with tearing strength and cold-extracted pH in naturally aged commercial paper. These findings support the use of AE signals to monitor the preservation level of old and valuable paper materials.

1. Objectives

The deterioration of books held in libraries and other archives is a widespread and serious problem. Paper deterioration in libraries and archives has often been investigated using sensory methods. In many cases, subjective judgment by human senses has been better for quality evaluation than objective testing. Objective tests are needed, however, because the reliability of subjective judgment depends upon the experience of each sensory testing panel.

Acoustic emission (AE) monitoring, which is non-destructive and monitors high frequency sounds emitted by a material when it is under stress, has been shown to reflect the onset and progression of small-scale damage. In this paper, a new method of measuring the strength of valuable deteriorating papers through the use of AE monitoring (Sonoda el al. 2004; Okayama and Sato 2007) is presented and the applicability of AE monitoring for the evaluation of naturally aged commercial papers and old book papers discussed.

2. AE principles and devices

AE is defined as the class of phenomena in which transient elastic waves are generated by the rapid release of energy from localized sources within a material. The ring-down count, which is commonly measured as an index of AE activity, is defined as the number of times the sensor signal exceeds a counter threshold (Fig. 1). Figure 2 illustrates the different AE parameters.

We used an AE sensor (3 mm in diameter) that was mounted on the upper platen of a motor-driven compression tester. A paper sample (approximately 10 × 10 mm) was placed on a thin rubber plate supported by the lower platen of the compression tester (Fig. 3). The paper sample was compressed slowly at constant rate of speed by the sensor. The compression speed of 10 mm min^{-1} was selected in this experiment to complete the measurement within 30 seconds. Photographs of the AE monitoring devices are shown in Figure 4.

The AE sensor, with a resonance frequency equal to 300 kHz, measured the AE signals. Preamplifiers with a 40 dB gain, together with a band pass filter (100 kHz–1 MHz) were also used; the amplifier gain was also 40 dB. The output from the sensor was processed in an AE processor using a threshold value of 2.2 V.

3. Applicability of AE monitoring for the evaluation of naturally aged commercial paper

To determine whether AE monitoring could effectively discriminate between naturally aged commercial papers, ring-down count is compared with conventional physical properties of paper. For this purpose, seven commercial wood-free papers were used to investigate the AE measurements. These papers were produced in 1981 and naturally aged for 25 years at 20°C and 65% relative humidity.

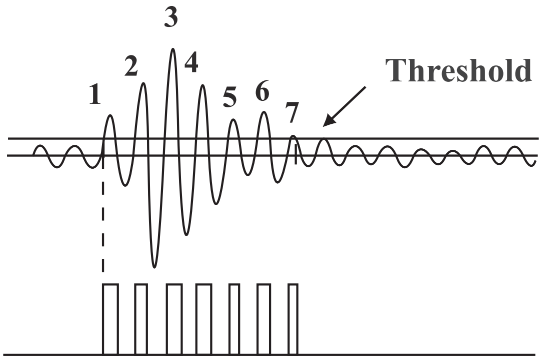

Fig. 1 Scheme of ring-down count of 7

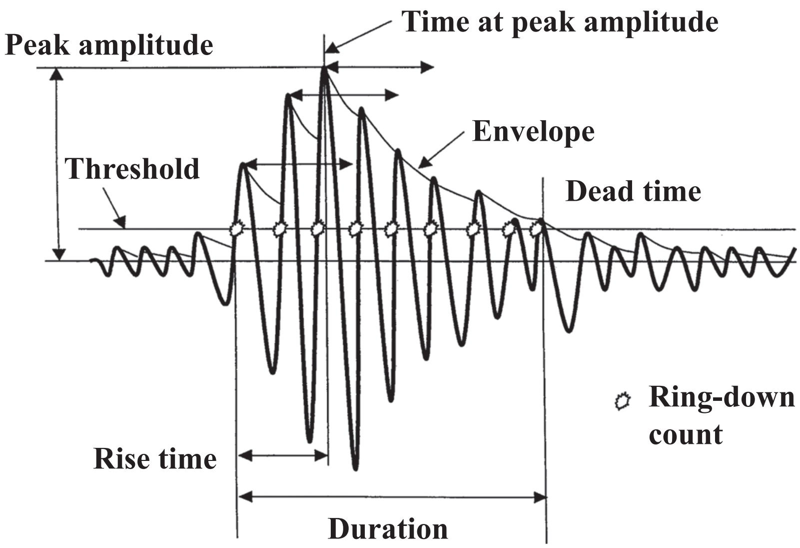

Fig. 2 AE parameters

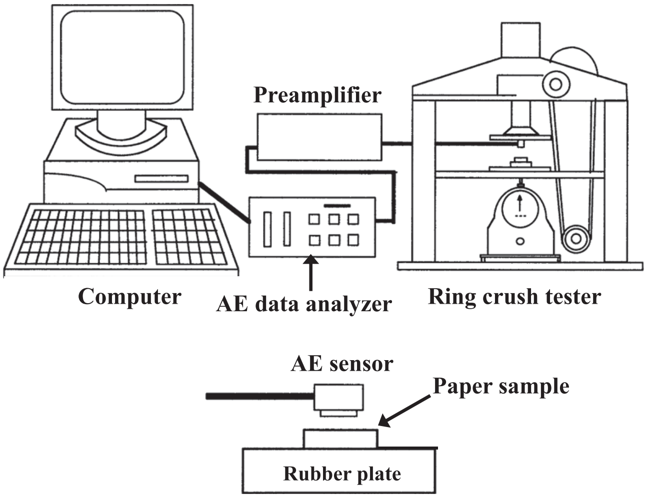

Fig. 3 AE monitoring system for the assessment of deteriorated paper

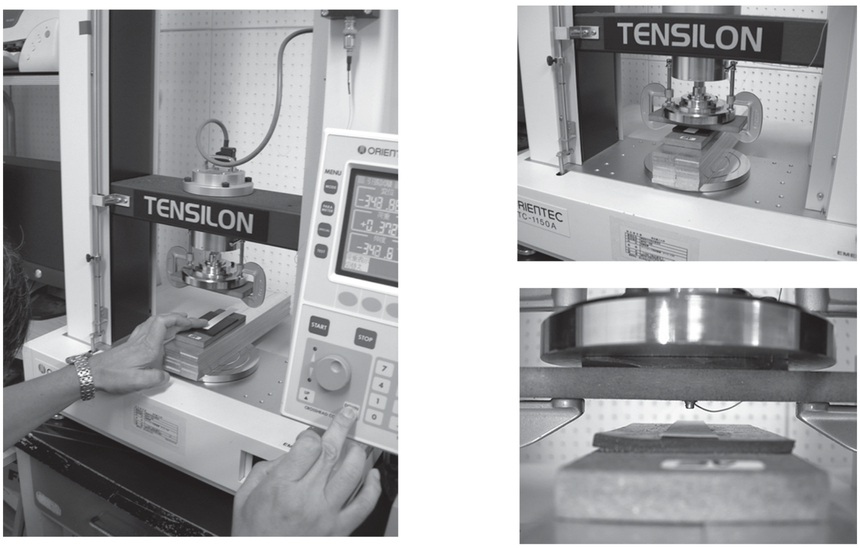

Fig. 4 AE devices used

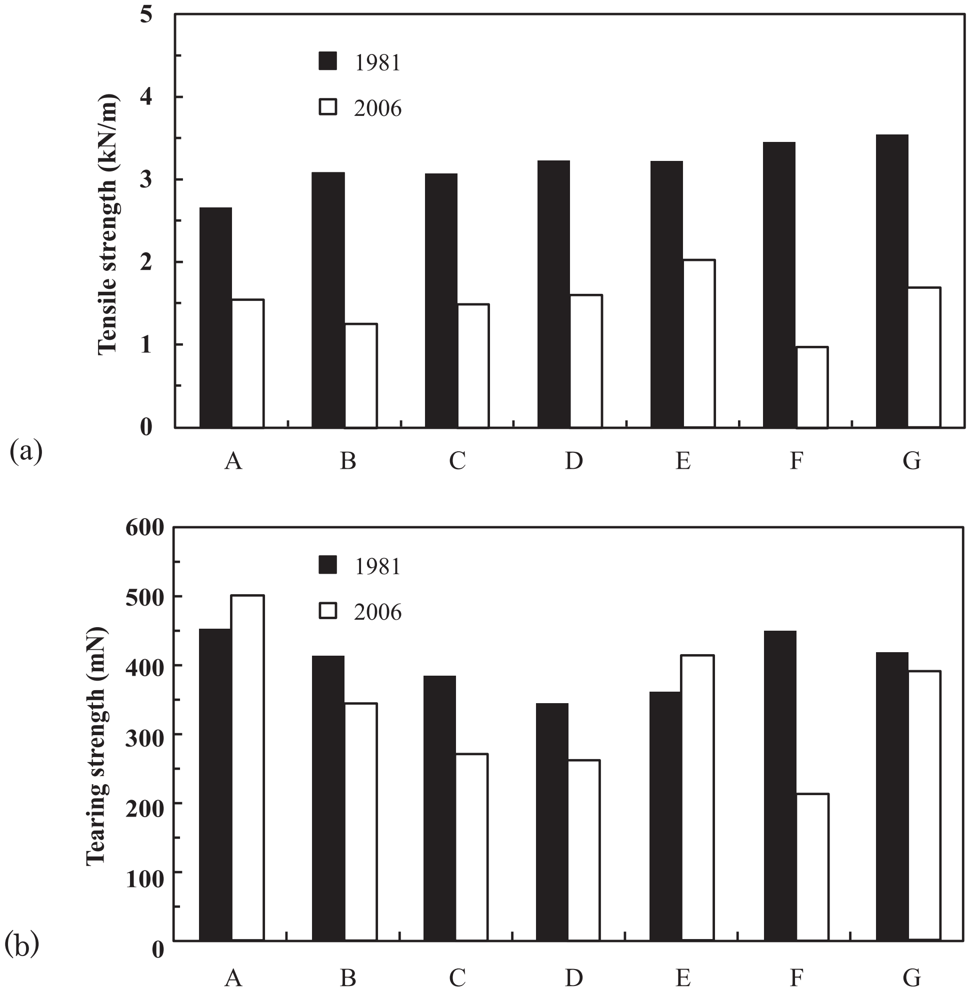

Fig. 5 (a) Tensile strength and (b) tearing strength of wood-free papers measured in 1981 and again in 2006 (paper pH: A = 8.2, B = 4.9, C = 4.4, D = 4.9, E = 7.7, F = 4.7 and G = 5.5)

Figure 5a shows changes in the tensile strength of the sample papers in 1981 and 2006. The tensile strength of the papers decreased considerably during the 25 years of natural ageing.

Acidic wood-free papers B, C, D, F and G showed decreases in tearing strength after the 25 years of natural ageing. However, there was no loss in tearing strength in the acid-free papers A and E (Fig. 5b). This result might indicate that there was no decrease in fibre strength in acid-free papers despite the considerable decrease in the strength of interfibre bonding during natural ageing.

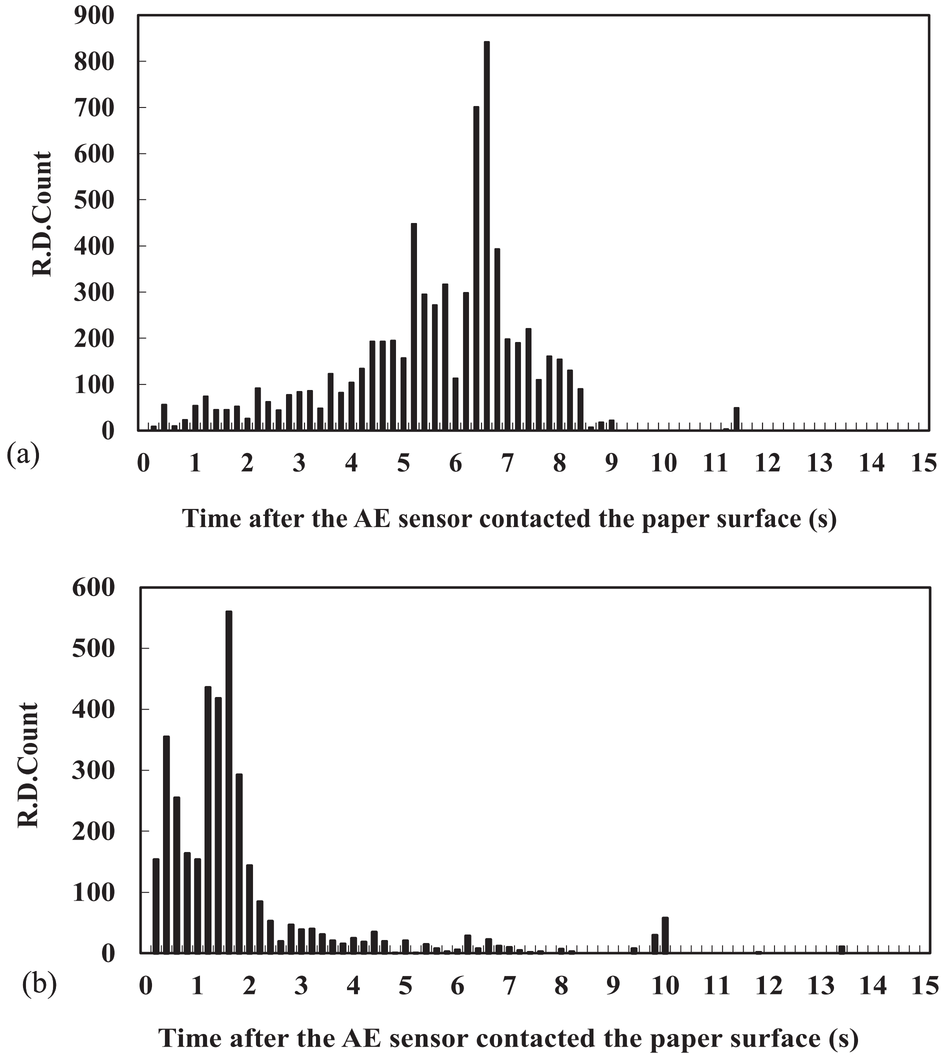

Fig. 6 Distribution of the ring-down counts with time after 25 years of natural ageing: (a) acid-free commercial paper A and (b) acidic commercial paper D

Figure 6 shows the distribution of the ring-down counts with time for an acid-free commercial paper A and an acidic commercial paper D after 25 years of natural ageing. There were some sharp and narrowly distributed peaks for both papers. The maximum AE ring-down count occurred 6.5 s after the AE sensor contacted the surface of the acid-free paper, whereas it occurred much earlier in the acidic paper. In general, the deterioration rate for acidic wood-free paper is faster than that of neutral wood-free paper because of the acidity, and the time until the maximum AE ring-down count in the acidic paper was considerably shorter than that of acid-free paper.

4. Applicability of AE monitoring for the evaluation of old book paper

Evaluation of old deteriorated books is complicated by factors such as the fibrous and chemical composition of the paper and the conditions of the papermaking process, as well as by technical means of assessment. Sixteen old books were selected from different periods. Identification of pulp fibres was performed according to ISO 9184-4 using Graff C reagent.

Table 1 summarizes the fibre composition of the sample paper. The books published in the first quarter of the twentieth century were composed of softwood chemical pulp, mechanical pulp and cotton pulp. Softwood sulfite pulp became ubiquitous in books published from 1933 to 1944. Books published in the second half of the twentieth-century contained a large amount of hardwood kraft pulp (Table 2).

Table 1 Fibre composition of samples of paper from books published in the early 1900s (%)

Year of issue	Softwood chemical pulp fibres	Mechanical pulp fibres	Cotton pulp fibres	Non-wood pulp fibres
1917	5	75	20	0
1919	30	60	10	Trace
1923	55	10	20	15
1924	75	5	20	Trace
1933	100	0	0	0
1937	100	Trace	0	Trace
1941	100	0	0	0
1944	50	50	0	0

Table 2 Fibre composition of samples of paper from books published in the latter half of the 1900s (%)

Year of issue	Softwood chemical pulp fibres	Hardwood chemical pulp fibres	Mechanical pulp fibres
1955	35	65	Trace
1956	10	90	0
1960	20	70	10
1963	0	90	10
1970	Trace	100	0
1973	0	100	0
1983	Trace	100	0
1986	0	100	0

The AE ring-down count for a typical acidic paper sample from an old book in poor condition is shown in Figure 7. This book was published during the Second World War, and the paper contains both softwood sulfite pulp and mechanical pulp because of economic conditions at the time. The time taken to reach the maximum AE ring-down count was notably short in this sample.

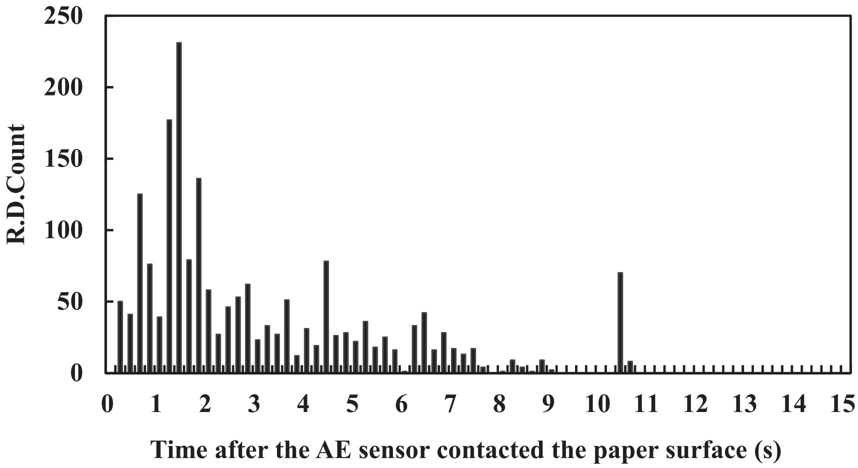

Fig. 7 Distribution of AE ring-down counts of a paper sample from an acidic book published in 1944 in poor condition

Figure 8 shows the AE ring-down count for paper from a book published in 1983 and preserved in good condition. The time lapse until the maximum AE ring-down count was longer than that of the sample taken from a book in poor condition (Fig. 8).

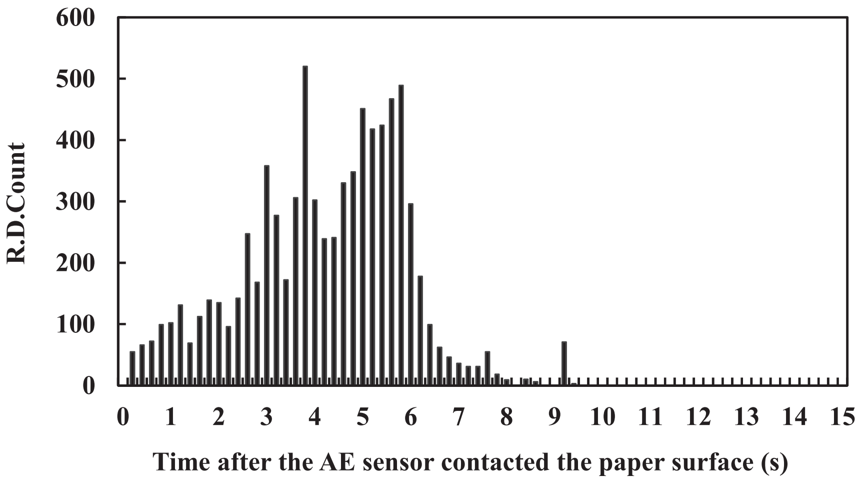

Fig. 8 Distribution of ring-down counts of a sample of paper from an acidic book published in 1983 in good condition

The relationship between year of issue and the elapsed time for maximum AE ring-down count is summarized in Figure 9. The time of the maximum ring-down count may not clearly depend upon the year of publication.

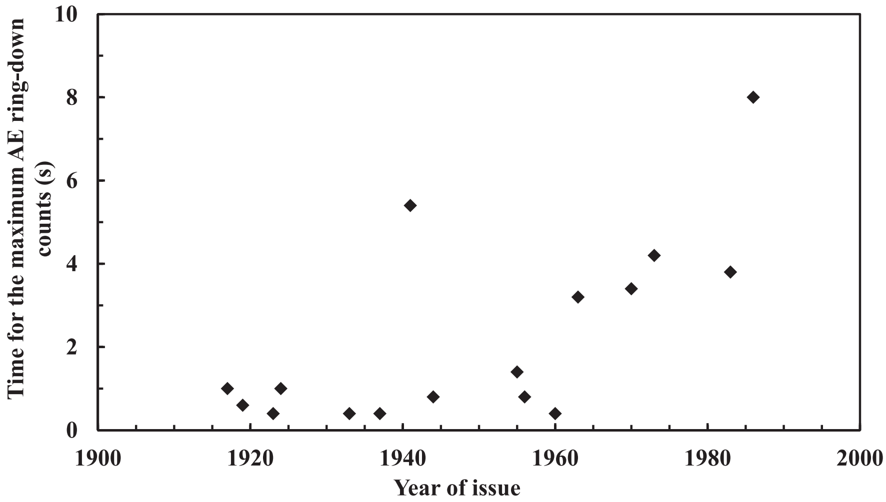

Fig. 9 Year of publication and elapsed time to the maximum AE ring-down counts of paper samples from old books

In general, an increase in the basis weight of paper will lead to increased paper strength. However, the elapsed time until the maximum AE ring-down count was not correlated with the basis weight of samples taken from deteriorated books (Fig. 10).

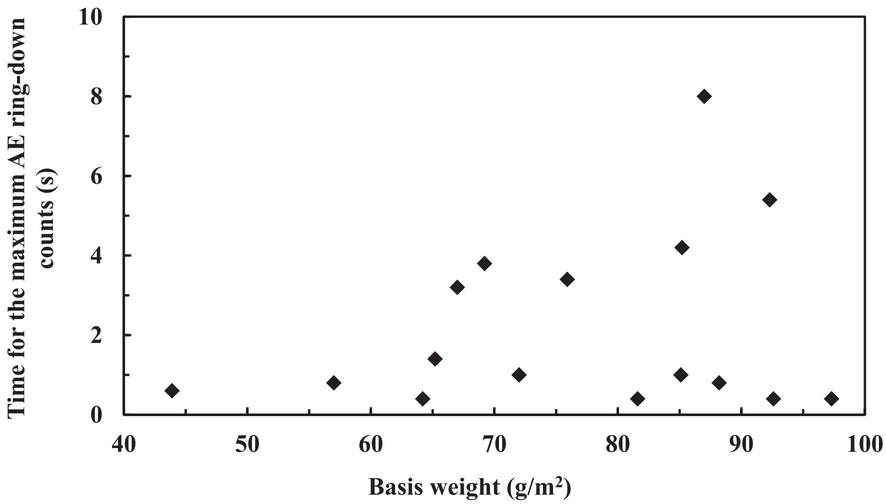

Fig. 10 Basis weight and elapsed time to the maximum ring-down counts of paper samples from old books

The MIT folding endurance test has been applied to detect strength decreases induced by deterioration of paper by ageing. This is due to the fact that folding endurance is the most sensitive property reflecting paper deterioration. Figure 11 shows the results of the MIT double-fold test on the paper samples from the deteriorated books, along with the elapsed time to the maximum AE ring-down counts.

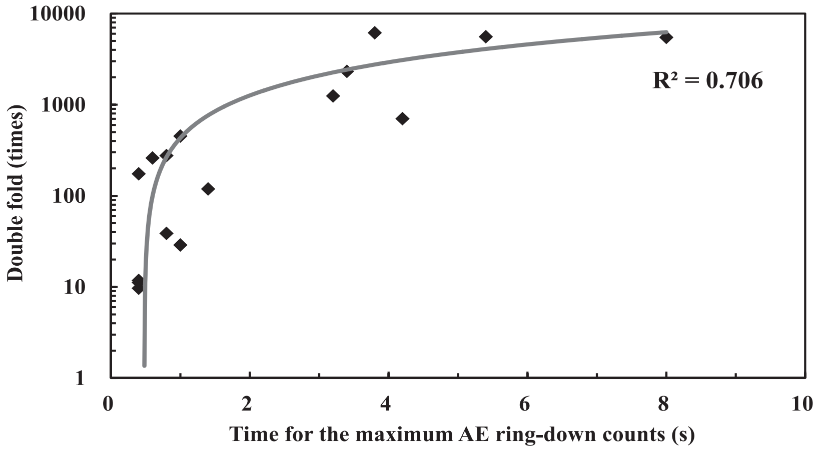

Fig. 11 Folding endurance and elapsed time to the maximum AE ring-down counts of paper samples from old books

The folding endurance test shows very wide statistical numerical results. The Elmendorf tearing strength has been confirmed as the most suitable test for the assessment of paper deterioration in terms of strength. Tearing strength was significantly correlated with the elapsed time to the maximum AE ring-down counts in the samples (Fig. 12).

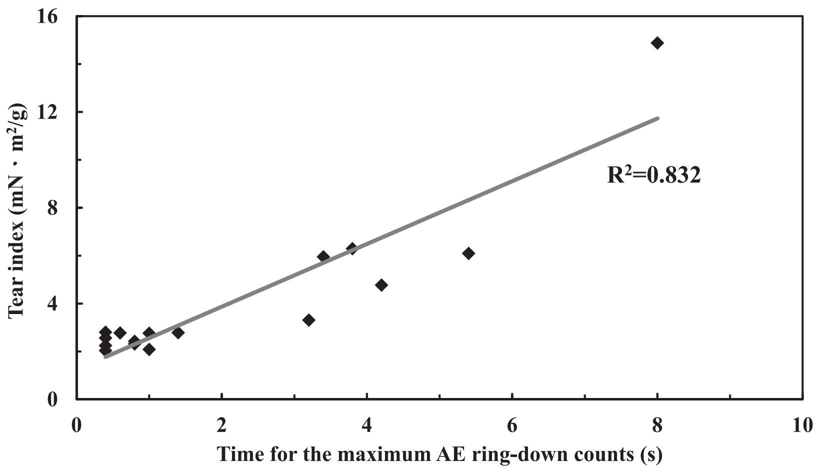

Fig. 12 Tearing strength and elapsed time to the maximum AE ring-down counts of paper samples from old books

5. Observations on the applicability of AE monitoring for the evaluation of natural aged paper

We combined the results of the naturally aged wood-free papers with those of the deteriorated book samples in Figure 13. The elapsed time to the maximum AE ring-down count of all naturally aged papers showed a similar tendency as the book samples in terms of tearing strength.

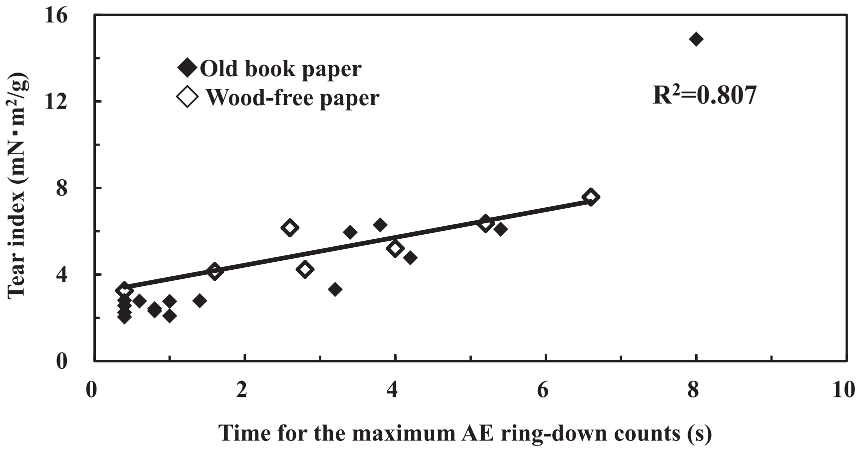

Fig. 13 Tearing strength and elapse time to the maximum AE ring-down counts of naturally aged paper and book paper samples

On the other hand, the correlation between tensile strength and the elapsed time to the maximum AE ring-down count was lower than that of tearing strength and time (Fig. 14).

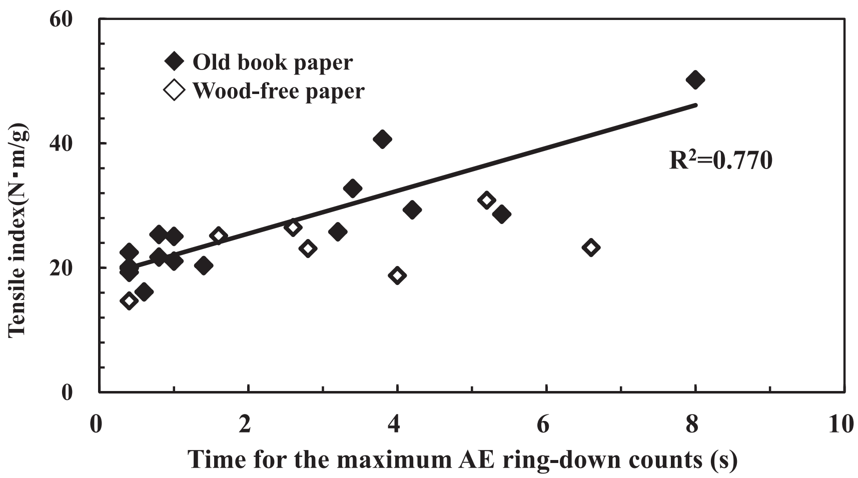

Fig. 14 Tensile strength and elapsed time to the maximum AE ring-down counts of naturally aged papers and book paper samples

The pH of all naturally aged papers was also correlated with the elapsed time to the maximum AE ring-down count (Fig. 15).

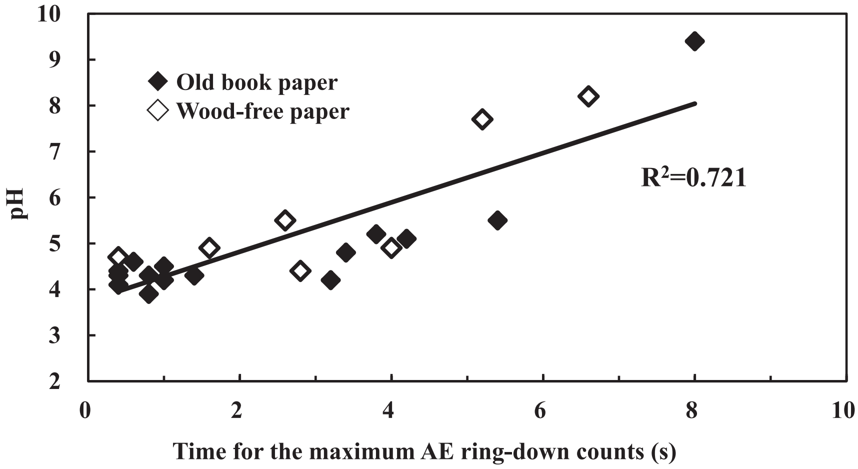

Fig. 15 Cold-extracted pH and elapsed time to the maximum AE ring-down counts of natural aged papers and book paper samples

6. Conclusions

These results lead to the following conclusions:

- The elapsed time from the moment of AE sensor contact to the maximum AE ring-down count is an indicator of the extent of deterioration of paper.
- The elapsed time to the maximum AE ring-down count for acidic paper damaged by natural ageing was shorter than that of acid-free paper.
- Changes in the elapsed time to maximum AE ring-down count in samples of old book paper and our naturally aged paper samples were correlated with changes in tearing strength, folding endurance, tensile strength and paper pH.

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