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## Research on the Conservation of Paper and Books and New Techniques for Evaluating Paper Deterioration

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## **Research on the Conservation of Paper and Books and New Techniques for Evaluating Paper Deterioration**

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In March 1998, Kyocera Co., Ltd. donated approximately 13,000 volumes of British Parliamentary Papers dating from 1801 to 1986 to the National Museum of Ethnology in Japan. Examination of some of the Papers, however, was either very difficult or impossible because of the fragility of the paper. The National Museum of Ethnology, in collaboration with other institutions, decided to conduct a study on ways of evaluating paper deterioration and on strengthening degraded papers. In this paper, a new evaluation method for paper deterioration tentatively called the “rolling test” is described. The paper to be tested is rolled using cylinders of different diameters, and paper that can be safely rolled on cylinders of smaller diameters is considered to be more “flexible”. The correlation between the rolling test and time of artificial ageing was studied using acidic wood free papers (dated 1981) artificially aged at  $105 \pm 2^\circ\text{C}$  for 0, 1, 2, 3, 4, 5, 6, 8, 12, 14, 16, 20, 24, 26, 28 and 32 weeks. The relationship between conventional mechanical measurements (tearing strength, folding endurance, tensile strength, and zero-span tensile strength) and the rolling test was evaluated using the same paper samples. These preliminary tests suggest that the rolling test permits the evaluation of paper samples that are too weak to be properly measured by ordinary mechanical measurements. The application of the rolling test to the Kyocera Collection of British Parliamentary Papers is also described.

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## 1. Introduction and background

The National Museum of Ethnology in Japan was established in 1974 as an Inter-University Research Institute, and in April 2004, it made a fresh start as a member of the National Institutes for the Humanities. The Museum functions as a research institute equipped with a museum. It serves as a research center for anthropology and ethnology, and the research results of the Museum are open to the public through exhibitions. In addition, the School of Cultural and Social Studies of the Graduate University for Advanced Studies, based at the Inter-University Research Institute, is located at the Museum.

In March 1998, Kyocera Co., Ltd. donated approximately 13,000 volumes of British Parliamentary Papers dating from 1801 to 1886 to the Museum on the condition that they would be made available to a wide range of researchers. With less than 1% of the Papers missing, they are considered to be the most complete original version of the British Parliamentary Papers available for researchers in the world. To provide safe access to the collection, preventive conservation measures were undertaken (Fig. 1). The volumes with original covers in an advanced state of deterioration were stored in neutral archival boxes, the non-original covers in a poor state of conservation were replaced with new ones, and the volumes

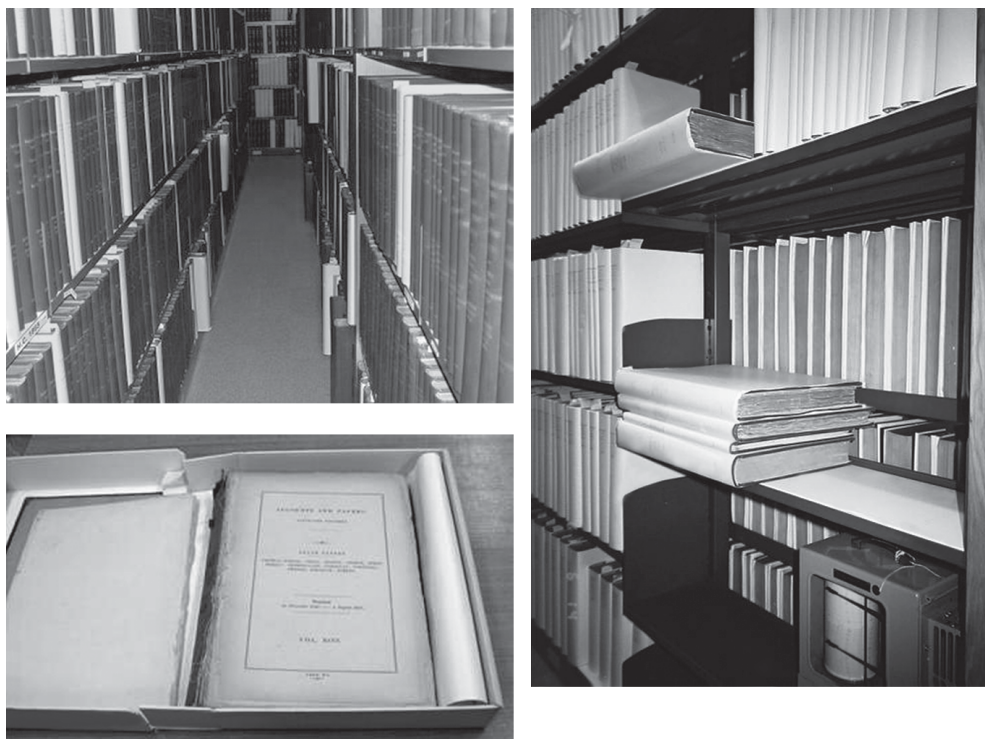


Fig. 1 British Parliamentary Papers at the National Museum of Ethnology, Japan (in 2005)

that need to be carefully handled were wrapped with neutral paper. In April 2006, the Papers were transferred to the Center for Integrated Area Studies at Kyoto University. The collection is open to the public at the Kyoto University Library.

Because of the fragility of the paper, perusal of some of the Papers was either very difficult or impossible. Supported by researchers who desired to see the Papers in their original form and by the donor, who wanted to assist in the realization of such desires, the Museum, in collaboration with other institutions, has been conducting a basic study on evaluating paper deterioration and on strengthening degraded paper. An essential part of the research project has been supported by the Grants-in-Aid for Scientific Research from the Japan Society for the Promotion of Science.

An appropriate method of strengthening must be selected in accordance with the degree of deterioration (Sonoda (ed.) 2004). For example, strengthening through the use of cellulose derivatives is applicable to paper that is not in an advanced stage of deterioration (Seki et al. 2005, 2010b). For more deteriorated paper, a more radical mechanical treatment such as paper splitting may deserve further investigation (Seki et al. 2010a). Also a new possibility, such as strengthening using fleece fibers or nanofibers may be worth examining in the future.

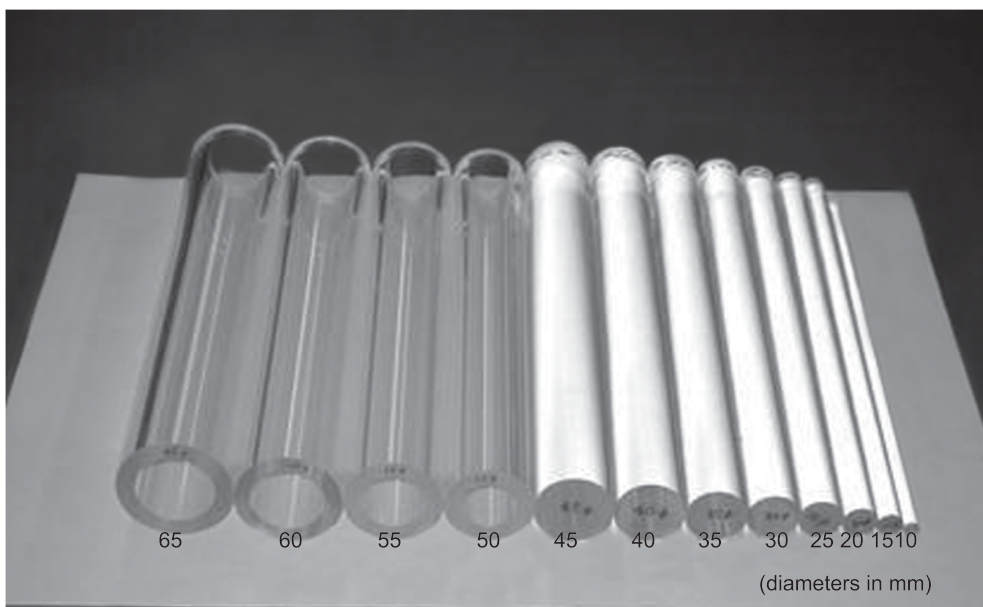
When dealing with strengthening degraded paper, many aspects need to be considered: At what stage of damage should treatment start? What is the minimum paper strength necessary so that a volume can be made available for use? To what extent can we conduct treatment? Only when these questions are answered and standards are established, can we effectively select the appropriate strengthening method.

For this purpose, we conducted research on different techniques of evaluating paper deterioration, such as acoustic emission and pyrolysis-gas chromatography (see the following papers in this section), and sensory judgment based on the experience of restorers and librarians. As a result, an original method tentatively called “the rolling test” was devised (Sonoda et al. 2004) and revised (Sonoda et al. 2011). We evaluated the rolling test by conducting experiments on artificially aged paper and by comparing the results of the rolling test with other standard mechanical testing methods. We also tested the method on the naturally aged papers in the collection.

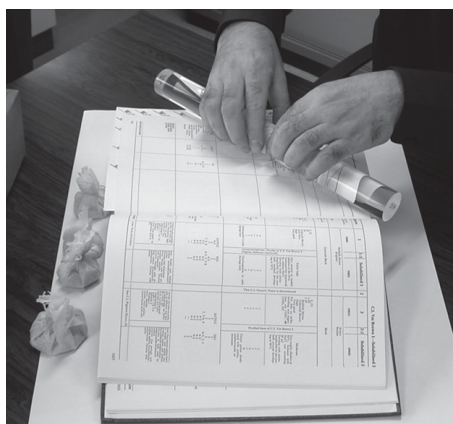
## 2. The rolling test

The rolling test is performed using acrylic cylinders with different diameters (10–65 mm in diameter, with intervals of 5 mm; Fig. 2). Initially, the test was performed either by rolling parallel to the page or by rolling from a corner of a page (Sonoda et al. 2004). The latter method was ultimately adopted as the standard test procedure because it is less affected by the direction of the fibers (Sonoda et al. 2011).

In the method, a piece of paper is first rolled around a cylinder 45 mm in diameter (65 mm if the paper is heavily deteriorated) from a corner, forming a 45° angle to the page (Fig. 3). If the page is rolled safely, without any wrinkles, tears or any kind of resistance, the same test is performed using a narrower cylinder. As soon as any sign of resistance appears, rolling is stopped, and the corresponding diameter roller used is noted as the final result (Sonoda et al. 2011).



**Fig. 2** Acrylic cylinders used for the rolling test



**Fig. 3** The rolling test

### **3. Comparison between conventional mechanical measurements and the rolling test**

Papers at varying levels of deterioration or brittleness were deliberately prepared through accelerated ageing. Naturally aged acidic wood free papers (dated 1981) were artificially aged at  $105 \pm 2^\circ\text{C}$  for 0, 1, 2, 3, 4, 5, 6, 8, 12, 14, 16, 20, 24, 26, 28 and 32 weeks in accordance

with JIS P8154-1 “Paper and board—Accelerated ageing—Part 1: Dry heat treatment at 105°C”. Standard mechanical measurements were then performed as described below in a temperature and humidity controlled laboratory ( $23 \pm 1^\circ\text{C}$ ,  $50 \pm 2\%$  RH) (Sonoda et al. 2011).

### 3.1 Tearing strength

Tearing strength was performed using an Elmendorf tearing tester in compliance with ISO 1974. The load of the apparatus was reduced to one-third, and the sample paper was layered fourfold and torn perpendicularly to the fiber direction. As seen in Figure 4, the tearing strength measurement could not be performed for paper samples artificially aged for more than 12 weeks because of their brittleness.

### 3.2 Folding endurance

Folding endurance was measured by using an MIT-folding tester in accordance with ISO 5626. The load of the tester was reduced to 2.94 N and applied lengthwise. The test could not be performed for paper samples artificially aged for more than 12 weeks (Fig. 5).

### 3.3 Tensile strength

Tensile strength was measured by using a tensile-testing apparatus with a constant rate of elongation in accordance with ISO 1924-2 (Fig. 6).

### 3.4 Zero-span tensile strength

Zero-span tensile strength was measured lengthwise with a zero-span tensile strength tester in compliance with ISO 15361 (Fig. 7).

### 3.5 The rolling test

The rolling test was applied according to the methodology described in the previous chapter (Fig. 8).

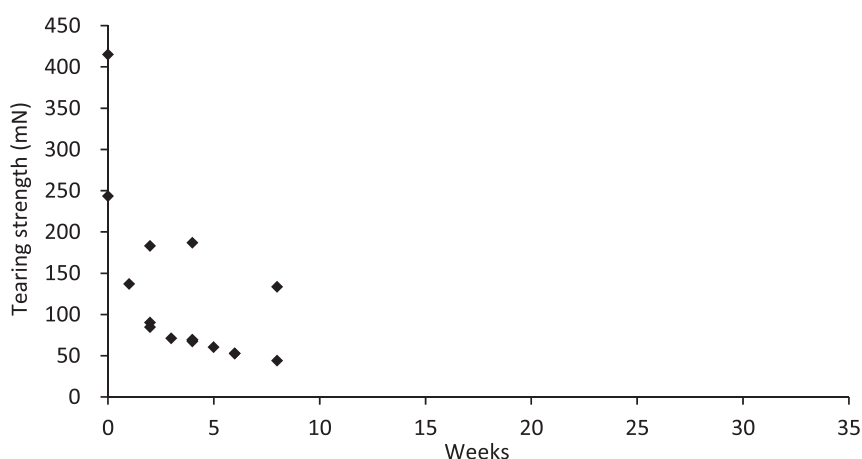


Fig. 4 Relationship between tearing strength and accelerated ageing

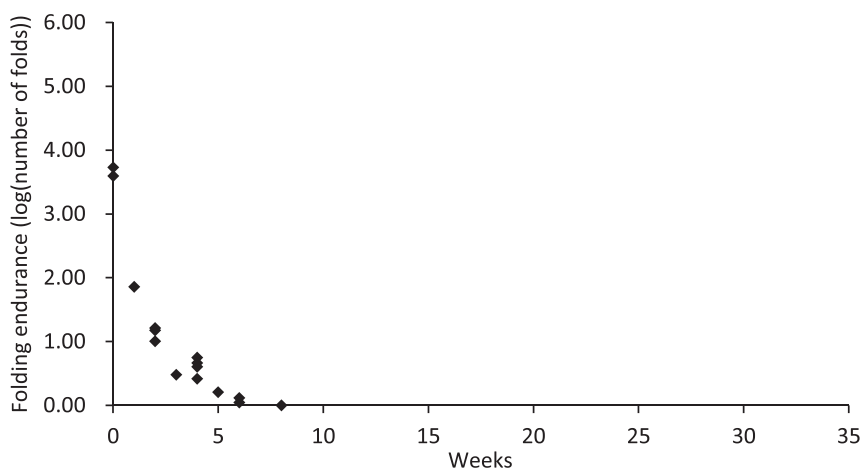


Fig. 5 Relationship between folding endurance and accelerated ageing

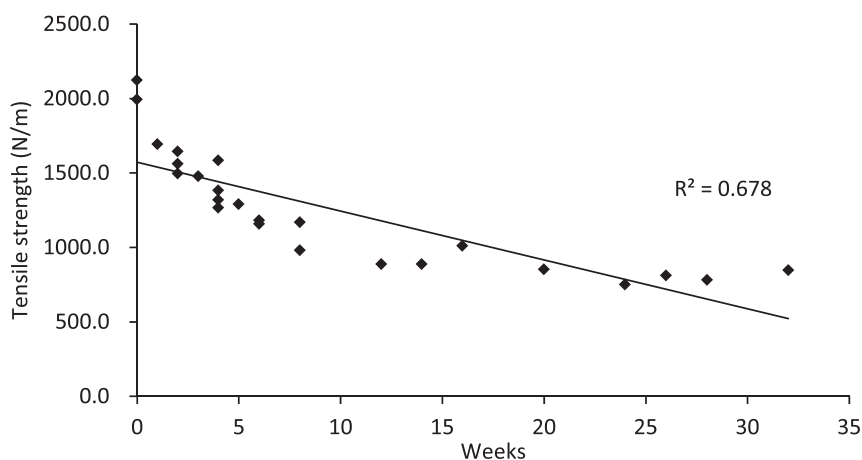


Fig. 6 Relationship between tensile strength and accelerated ageing

### 3.6 Observations

The results shown in Figures 4 to 8 indicate that tearing strength and the folding endurance test are suitable for the characterization of papers that are not deteriorated, for example, commercially available papers, whereas tensile strength, zero-span tensile strength and the rolling test seem to be applicable to the study of deteriorated papers. The decision coefficients for tensile strength, zero-span tensile strength and the rolling test were  $R^2=0.678$ , 0.586 and 0.835, respectively, and the respective correlation coefficients were  $R=0.82$ , 0.76, and 0.91. Although tensile strength and zero-span tensile strength were fairly well correlated with artificial age, the correlation was stronger for the rolling test.

Figures 9 and 10 respectively show the relationships between the rolling test and tensile

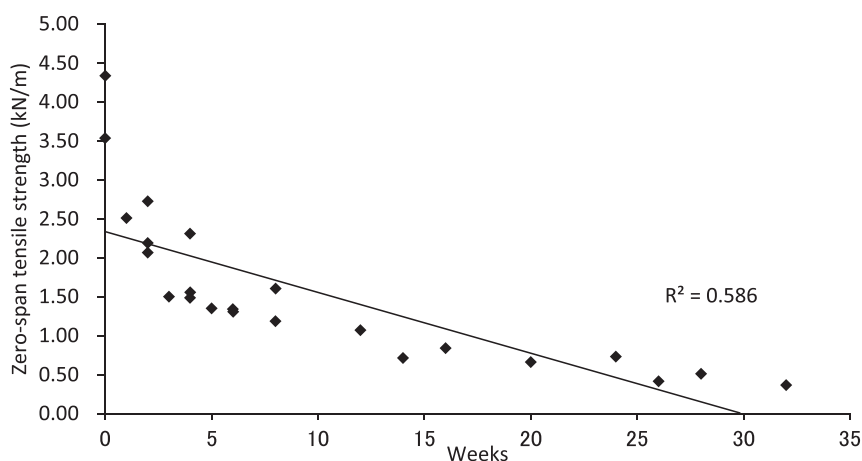


Fig. 7 Relationship between zero-span tensile strength and accelerated ageing (Sonoda et al. 2011)

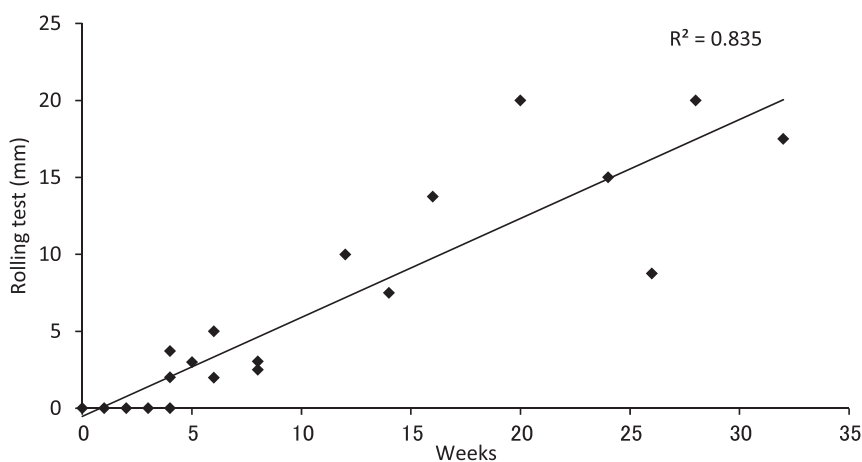


Fig. 8 Relationship between the rolling test and accelerated ageing (Sonoda et al. 2011)

strength results and between the rolling test and zero-span tensile strength results. No clear correlation between the rolling test and the two measurements was observed, but the figures do illustrate differences between the mechanical measurements and the rolling test. In case of aged and weakened paper, the rolling test may be a more effective measurement method because it provides distinctions not afforded by conventional methods (the encircled data in Figs. 9 and 10).

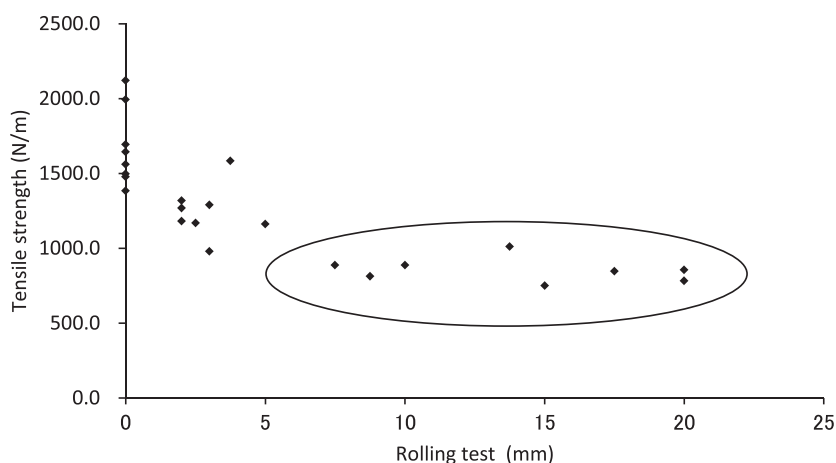


Fig. 9 Correlation between the rolling test and tensile strength measurement

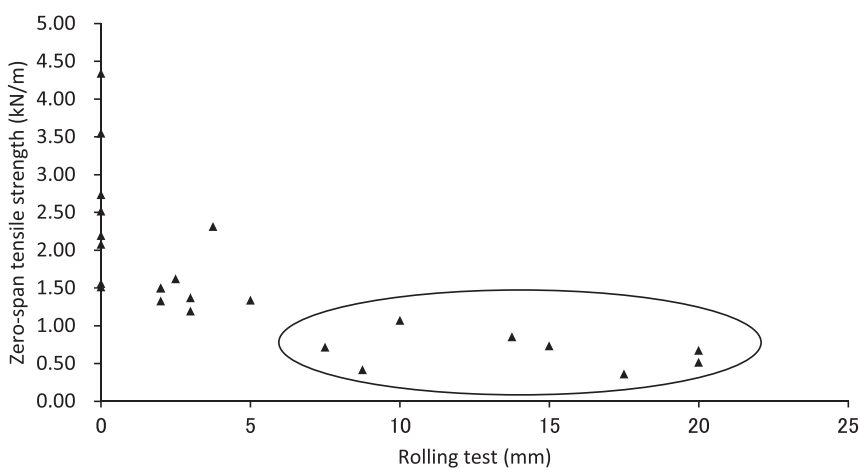
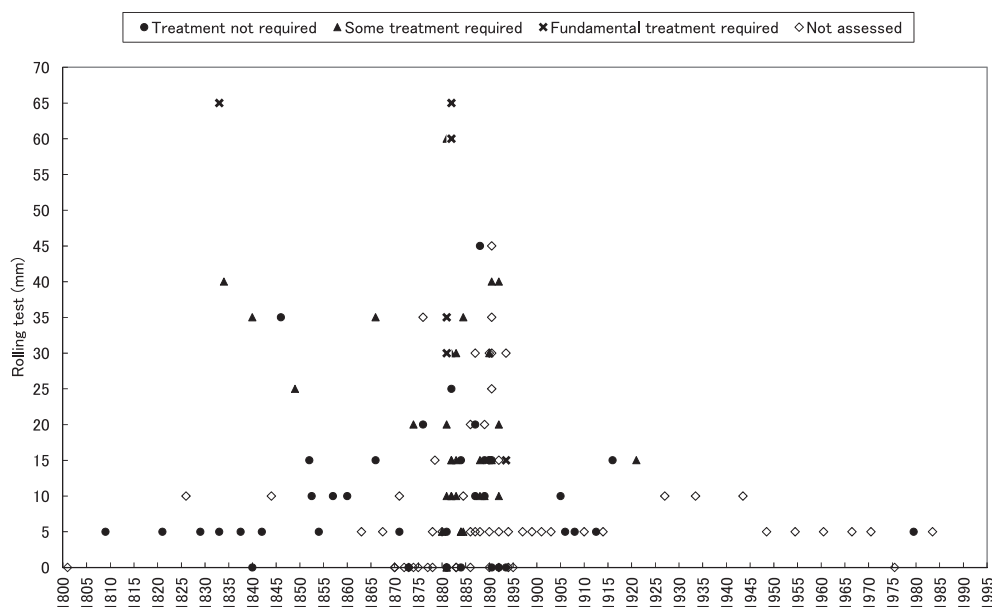


Fig. 10 Correlation between the rolling test and zero-span tensile strength measurement

#### 4. Application of the rolling test to naturally aged papers: the Kyocera Collection of British Parliamentary Papers

The rolling test was applied on a sample of pages from the Kyocera Collection of the British Parliamentary Papers. From nearly 13,000 volumes, 137 were selected, 47 through a systematic sampling of every 200 volumes from 1801 to 1983, and 90 that focused on the problematic years of 1850–1900, where degraded acidic papers are encountered most frequently.

To ensure the results were comparable across all tests, the rolling test was performed by one evaluator. For each sample volume, one page without existing tears, folds or other anomalies was chosen. At the same time, five people (one librarian, one paper conservator,



**Fig. 11** Results of the rolling test and evaluations of treatment requirements for a sample of volumes from the Kyocera Collection of British Parliamentary Papers

one archivist, one conservation scientist and one paper chemist) judged if the respective volume needed any conservation treatment. The results were classified into three categories: no conservation treatment needed, some treatment needed and fundamental treatment needed (Fig. 11).

Papers that could not be rolled safely with a cylinder diameter of 15 mm were mostly from the 1860s to the 1890s, the period in which deterioration is frequently encountered. Given that the number of books tested for each 50-year period differed, we calculated the percentages of pages that were able to be rolled onto cylinders with a diameter of more than 15 mm and of no more than 15 mm for the four 50-year periods studied. For the samples from the second half of the 1800 s, more than 40% of the samples were considered as relatively not flexible (Sonoda et al. 2011).

Almost all of the papers successfully rolled with a cylinder of 10 mm were judged as not needing any conservation treatment by the five evaluators and could thus be considered to be in good condition.

## 5. Summary

These preliminary tests suggest that the rolling test permits the evaluation of paper samples that are too weak to be measured by customary mechanical means. When evaluating whether a book requires conservation treatment, the degradation state of the entire page should be taken into consideration. In this sense, we think that the rolling test is an effective evaluation

method because it can be carried out on a larger area of the page than, for example, the double fold test.

A key benefit of the rolling test is that it is primarily non-destructive, which is an asset for the study of library and archival materials. Application of the rolling test to a sample of volumes from the Kyocera Collection of British Parliamentary Papers showed promising results. The use of the rolling test should be further examined using a wider variety of naturally aged papers.

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