HISTORY, ANALYSIS AND DATABASE OF TRADITIONALLY-HANDMADE JAPANESE PAPER

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ABSTRACT

First, the history of Japanese paper technology was overviewed. There were three major historic evolutions that occurred in a long history. The first evolution was use of shorter fibers from hemp to paper mulberry, Gampi, and Mitsumata fibers chronologically. This transition means that the choice of papermaking fiber sources oriented itself towards shorter fibers for good sheet formation and for reduced labor to cut long fibers. The second evolution was use of *Neri* for dispersing fibers in combination with flow sheet-forming method, that is, the third evolution both for good sheet formation to improve brush writability. Second, the technique to determine fiber orientation was introduced. Degree and angle of fiber orientation of handmade sheet surfaces depends on the forming screen motion, which are defined as two sheet-forming methods; the still sheet-forming and flow sheet-forming. Korean and Japanese papers manufactured by the traditional methods were well distinguished by this technique. Last, a new database system for paper properties of historic documents is in process of creation. It was proposed to share the datasheet format and finally the data of a lot of historical document paper between the three countries.

INTRODUCTION

Modern papermaking history, and traditional paper history and science have become more and more important as industrial and cultural resources, respectively to preserve and hand down to next generations. Scholars involved with these matters belong to a variety of fields such as preservation and restoration of paper cultural properties, records and archives sections of paper companies and paper industry, paper art, historical sciences, and pulping and paper sciences. This article refers to natural science, historical science and restoration technology related to traditional paper —Japanese paper— and consists of three chapters; brief history of Japanese paper technology and industry, a technique for prediction of hand sheet-forming methods by using fiber orientation determination, and a creation of paper property database of historic documents and proposal to share the database system and the practical data.

HISTRORY OF JAPANESE PAPER TECHNOLOGY AND INDUSTRY[1)]

Paper manufacturing began in ancient China. In East Asia, this technology passed first to Korea some time between the second and fourth centuries according to an ancient Korean record[2)] and then to Japan in 610 according to the Yamato Dynasty Chronicle of Japan. In the document, it is described that a Korean priest Doncho (曇徴), as an ambassador of the Goguryeo (高句麗) Dynasty, visited the dynasty government and instructed how to manufacture paper as well as paints with pigments, Chinese inks, and hydraulic mills for beating fibers.

Domestically, there have been several evolutions in papermaking technology. In view to historical transition of fiber sources for papermaking, cloth fibers such as hemp (*Cannabis sativa L.*, 大麻), ramie (*Boehmeria nivea.*, 苧麻), and linen (亜麻) were used initially. Later, however, the paper materials for ancient Japanese art and documents were made also from other bast fibers such as paper mulberry (*Broussonetia kazinoki Sieb.*, 楮, Kozo) as are contemporary handmade papers that are manufactured in the traditional ways. This fact is recorded in the Shoso-in (正倉院) documents as of 751 and it suggests that paper mulberry was widely used in those days. Then, use of Gampi (*Diplomorpha sikokiana*, 雁皮) started immediately next to paper mulberry. It seems that Mitsumata (*Edgeworthia chrysantha*, 三椏) started to be used almost in the same period, but the first year when use of Mitsumata was described in a document (order for papermaking work from Ieyasu Tokugawa, the founder of the Edo government) is 1598.

As listed in Table 1, the historic transition of fiber sources mentioned above is positioned as one of the important evolutions of papermaking technology for Japanese paper. Shorter fibers have advantages over longer ones because fiber flocculation can be avoided to manufacture homogeneous sheets for better brush writability. Hemp fibers about 100 mm long must have been cut to shorter pieces for that reason and the manual cutting work required a lot of time and energy. To reduce it, fiber sources used shifted to shorter fibers such as paper mulberry 10 mm long, Gampi 5 mm long, and then Mitsumata 4 mm long.

Table 1 Three major historic evolutions of Japanese paper

1.	Use of shorter fibers from hemp (大麻) to paper mulberry (楮), Gampi (雁皮), and Mitsumata (雁皮) fibers in the chronological order.
2.	Use of *Neri* for dispersing fibers for good sheet formation
3.	Flow sheet-forming methods for good sheet formation

The second one of the papermaking techniques typical of Japanese paper is use of a natural fiber-dispersing agent called *Neri*, a viscouse liquid extracted from roots of abelmosk (*Abelmoschus manihot*, 黄蜀葵). The use of *Neri* is regarded as a Japanese typical innovation by Japanese scholars in the field of Japanese paper culture. *Neri* includes polyuronic acids[3)] with anionic carboxyl groups that disperse fibers well by electrostatic force for good sheet formation and control of dehydration speed.

The third one is the flow sheet-forming method. In this method, a mould with a forming screen composed of bamboo splints is dipped into a vat containing beaten fibers suspended in water with some amount of *Neri*. The filled mould is lifted above the water and then moved back and forth or sideways, so the sheet becomes homogenized and excess fibers are thrown off. Several dips form one sheet, which is then transferred to a pile of paper to be pressed together followed by drying on wooden boards. The combination of the flow sheet-forming method and *Neri* provides a synergetic effect on homogeneity of sheet formation. The use of *Neri* and the flow sheet-forming method are speculated to have been initiated in the Nara Period (710-794) or the Heian Period (794-1192).

Since then until the beginning of the Meiji Period (1868-1912), wood-processing technology to manufacture forming screens had been improved as we can see the transition of the frequency of laid lines that constitute a forming screen. The Daitokuji documents (1168 - 1708) were surveyed for the historic transition of laid line frequency. Figure 1 shows that the laid line frequency decreased from 14 lines/sun ("sun" is the traditional Japanese unit of length equal to 30.3 mm) in the 12^{th} century to 19 lines/sun in the mid 16^{th} to early 18^{th} century. This measured frequency shows a good continuity with the data from Ryukoku University documents surveyed by Kato[4)]He mentioned that the frequency was a little less than 20 lines/sun from 17^{th} to the mid 18^{th} century and it increased suddenly to 20 to 30 lines/sun from the late 18^{th} to the early 20^{th} century.

As an industry, Japanese paper continued to increase the production scale with paper demand expansion. However, it started to compete with western paper when 7 western paper companies were established between 1872 and 1875. Around 1912, the productions of Japanese and western papers were reversed. The number of houses where paper is manufactured started to decline after peaking in 1902.

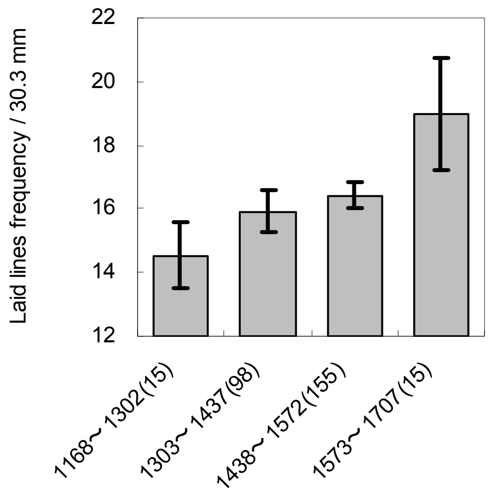

Fig. 1 Mean laid lines frequency determined every 135 years for Daitokuji documents papers. Figures in parentheses after year term indicate number of measured samples.

CHARACTERIZATION OF JAPANESE PAPER BY FIBER ORIENTATION DETERMINATION[5)]

Traditional sheet-forming processes used in the manufacture of Korean paper (韓紙) and Japanese paper (和紙) are classified into two methods, depending on the screen motion: the still sheet forming method (溜漉) and the flow sheet-forming method (流漉) as mentioned in the previous section. These two methods still remain the major hand-making paper technologies. The motion of the screen in the two methods is reflected in the fiber orientation of the paper in different manners. One can often easily find fibers running in a specific direction on paper surfaces. However, it is impossible to evaluate the degree of fiber orientation (anisotropy) or the exact direction (angle) objectively by visual inspection alone. An image analysis technique allows one to quantify the degree and angle of fiber orientation of paper surfaces nondestructively. The purpose of this work is to characterize the sheet-forming methods and technology used for manufacturing papers of historic documents.

Experimental – theory and methods

Statistically, fiber alignment is expressed as a fiber orientation distribution as a function of angle. As a consequence of the statistical calculation using FFT (Fast Fourier Transform), the fiber orientation degree and angle (the right direction from the view of the standing craftsman is assumed to be 0°) are determined as follows.[6)] First, a micrograph as a 256 grey-level image was trimmed to a size of 1024 × 1024 pixels (Figure 2a, for example) to facilitate the FFT computation. Second, the images were binarized using a dynamic threshold method of image partition (Figure 2b). FFT was computed with these binary images to obtain power spectra like that shown in Figure 2c, which was calculated from Figure 2b. The central bright region and its horizontal extension relate to the fiber orientation. To evaluate fiber orientation, amplitude (the square root of power) was added in the radial direction from the origin. That is, for each angle between 0 and 180° above the horizontal axis, the mean amplitude was calculated. If the mean amplitude values are plotted as a function of angle in polar coordinates, fiber orientation diagrams like the curve

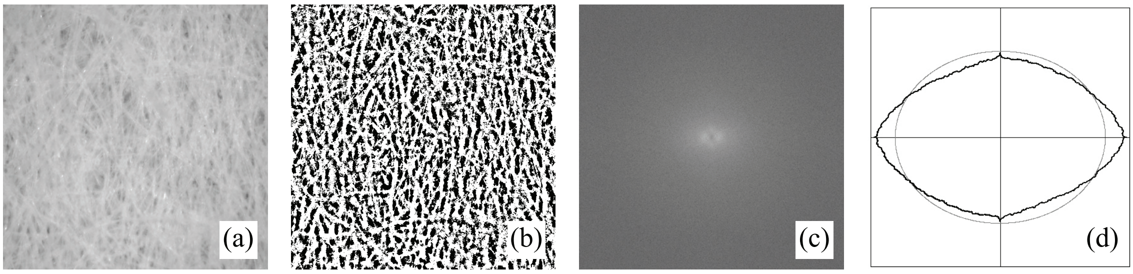

Fig. 2 Micrograph of screen side of Japanese H with digital optical microscope (a), binary image (b), FFT spectrum (c) and distribution diagram of overall fiber orientation (d).

drawn with the thicker line in Figure 2d are obtained. The elliptical curve drawn with the thinner line as an approximation has longer (L) and shorter (S) axes at right angles to each other. The angle of S (0<S<180º) represents the direction of fiber orientation. The magnitude of elongation, calculated as length L divided by length S, represents the degree of fiber orientation.

A digital microscope DG-2, Scholar Co. Ltd., Japan was used to acquire reflected light images of paper surfaces with a 100× magnification lens. Specimens were illuminated on a scanning stage at a low angle.

Experimental – samples

In the experiment, handsheets were prepared so as to simulate flow sheet-forming and still sheet-forming from a suspension of mulberry fibers after beating to 1000 revolutions with a PFI mill. *Neri* was added to the suspension. Bamboo splints of the screen were 0.1 mm thick and woven at 28 lines/sun. The papers prepared in this condition will be referred to as model papers in the following sections. In addition, contemporary papers manufactured using traditional methods in South Korea and Japan were examined to determine fiber orientation. The samples used were Mino paper with a basis weight of 61 g/m^2 (Japanese H) prepared by S. Hasegawa. Mino paper is one of the major Japanese paper products. Jangji of 57 g/m^2 (Korean J) and Uiryeong of 52 g/m^2 (Korean U) were made at craft studios in the traditional papermaking districts Uiryeong and Jangji, Korea, respectively.

Results and discussion

As Figure 2 shows, in the case of Japanese H, the degree of fiber orientation is very high and the orientation angle is almost 90°. In contrast, the distribution diagram of Korean J (Figure 3d) is relatively isotropic, indicating that there is no specified angle of fiber orientation. Accordingly, the fiber orientation degree is as low as 1.02.

Figure 4 shows the degree and angle of fiber orientation for the three kinds of contemporary

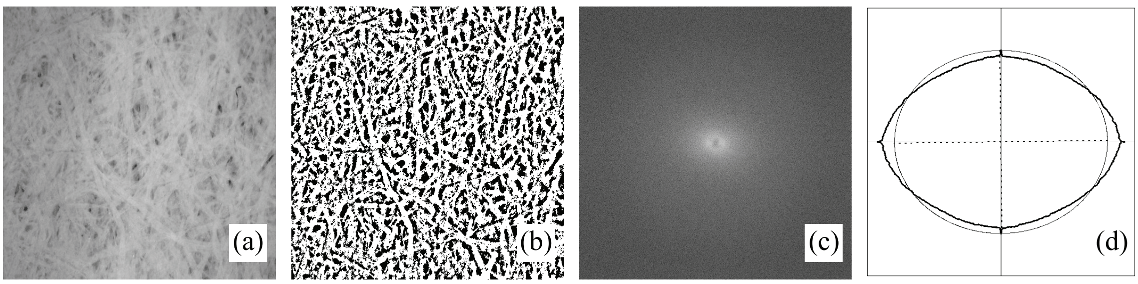

Fig. 3 Micrograph of screen side of Korean J with digital optical microscope (a), binary image (b), FFT spectrum (c) and distribution diagram of overall fiber orientation (d).

handmade papers. For the screen side, all the samples give high degrees of fiber orientation ranging from 1.16 to 1.22 and orientation angles of about 90°. For the top side (the other side of screen side), Japanese H gives a fairly high degree of fiber orientation, while Korean J and U show no fiber orientation because the degrees are almost equal to unity. The corresponding orientation angle of Japanese H is about 90°, although those of Korean J and U have very large 95% confidence intervals, denoted by the symmetrical error on the top of each thick bar in the figure. This result means that the determined orientation angles have large deviations and thus uncertain. The orientation angle of 90° means that the craftsman slanted the mould by lowering the edge on the far side from him as he regularly does. Exceptionally, the top side of Korean repair paper J gives an orientation angle of about 170°. However, the 95% confidence interval of the orientation angle is very large in this case, and the orientation degree is as low as 1.02. Therefore, it is reasonable to assume that this case indicates random orientation.

The general tendency of the data was to show the two-sided nature of fiber orientation degree indicating that the screen side always has higher degrees. Fiber orientation was examined with the model papers prepared in the laboratory by simulating typical motions of the traditional sheet formation. Figure 5 shows the degree and angle of fiber orientation obtained by the different sheet-forming methods. As expected, the flow sheet-forming method shows the highest value of orientation intensity (> 1.15), indicating strong fiber orientation, and the still sheet-forming method shows the lowest value (< 1.10), indicating random fiber distribution. The sequential flow and still sheet-forming method has intermediate degrees for the screen side, and the random orientation of the top side is as expected from the low degree.

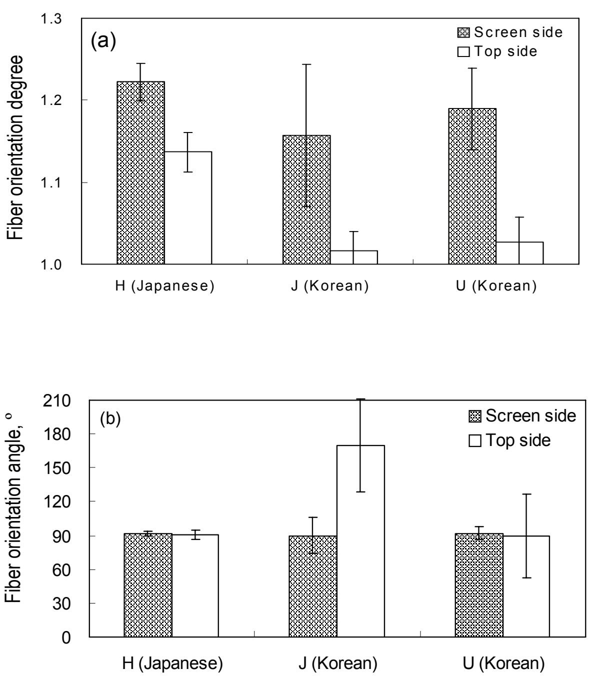

Fig. 4 Fibre orientation degree (a) and angle (b) of Korean and Japanese repair papers.

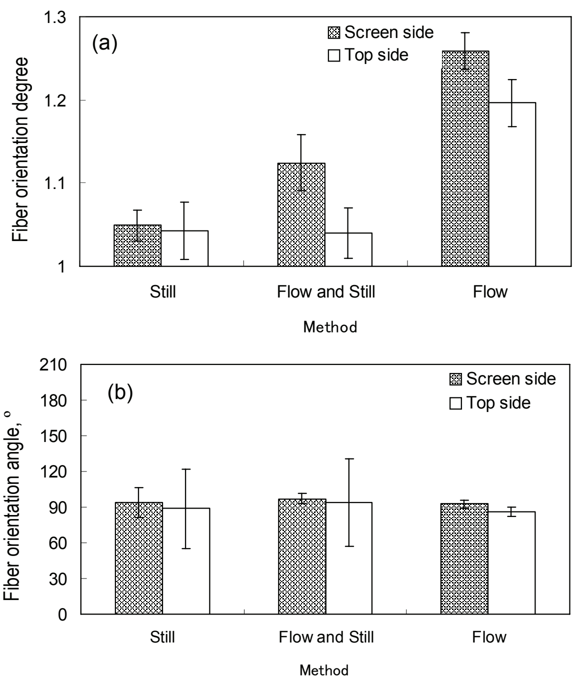

Fig. 5 Fibre orientation degree (a) and angle (b) of laboratory handmade papers prepared by three different methods of sheet forming.

PAPER PROPERTY DATABASE OF HISTORIC DOCUMENTS

Our research team of paper cultural heritage has two researcher groups in different fields; historical science and paper science. However, our team members together are now trying to create a nation-wide database on paper properties of historic documents. This effort is worth confirming historical evidence and reviewing historic papermaking technology.

Some paper properties are customarily measured and recorded before and after restoration of paper cultural heritage in restoration workshops. But, the format of the datasheet is not common to all of the workshops. One object of our project is to share the paper property data of many historic documents for information exchange and to create the database system as a platform for that purpose. In our new database system in process of creation, the datasheet shown in Figure 6 is proposed. This datasheet view is for browsing all the recorded data, and when input by restoration workers, user-friendly prompts appear for input assistance. In addition to document properties like document name and written age, and paper properties like dimension, basis weight, thickness, density, color and presence of starch as a filler, frequencies each of splint and chain lines are automatically calculated from a transmission image and its scale. Moreover, fiber orientation degree and angle can be also calculated from uploaded images by the built-in program.

This database system will help with classification of past Japanese paper. Traditional term based on the place of production is popularly used as a naming system of paper. But, it is logical to distinguish past paper by means of types of fiber sources, added components, structural characteristics like wavy wrinkles at surface, optical properties etc, as long as place of manufacture is unknown, as is common.

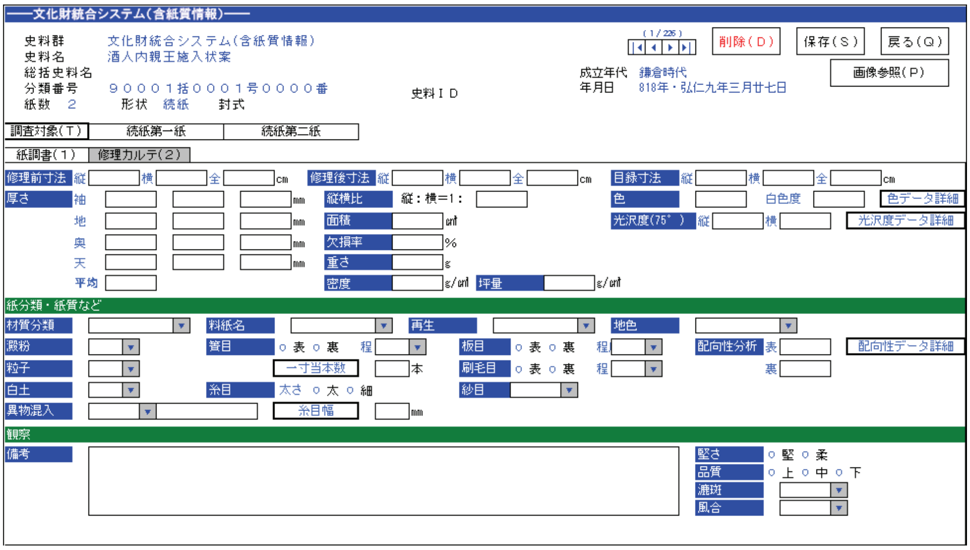

Fig. 6 Datasheet for recording paper properties of historical documents.

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