Analysis of Historical Documents from a Viewpoint of Paper Science

YOON-HEE HAN*, **TOSHIHARU ENOMAE**†, **AKIRA ISOGAI**‡,
HIROFUMI YAMAMOTO** and **MICHIHISA HOTATE****

*JSPS Postdoctoral Fellow, †Associate Professor, ‡Professor
**Professor of Historiographical Institute

*Paper Science Lab., Department of Biomaterial Sciences, Graduate School of Agricultural and Life Sciences
The University of Tokyo, Yayoi 1-1-1, Bunkyo-ku, Tokyo 113-8657, JAPAN

Currently affiliated with
*Historiographical Institute, The University of Tokyo, Hongo 7-3-1, Bunkyo-ku, Tokyo 113-8654, JAPAN

enomae@psl.fp.a.u-tokyo.ac.jp (Toshiharu Enomae)

ABSTRACT

Restoration of historical documents and arts has become important to inherit cultural properties. Most of historical documents were recorded on paper. Therefore, restoration of ancient papers is demanded and techniques for this purpose must be developed and sophisticated. In our study, several nondestructive methods for analyzing ancient paper have been developed. Image analysis using fast Fourier transform with suitable modifications was applied to optical micrographs of traditionally-handmade Korean and Japanese papers. This analysis determines the angle and anisotropy of fiber orientation of paper surfaces. Fiber orientation of traditionally-handmade Korean and Japanese papers was found to show their own characteristics in accordance with the motion of a papermaking screen made of bamboo splints. Consequently, the information on fiber orientation was found to be possible to distinguish the flow-sheet forming typical of Japanese paper and still- sheet forming typical of Korean paper. Moreover, the anisotropy was always higher for the screen side than for the top side, thus meaning that surface fiber orientation is possible to distinguish the two sides of paper of which papermaking history is unknown. An application of this technique to actual historical documents evidenced that wrapping papers were used as envelops with a lateral side up, namely, after rotating 90 degrees. A variety of cultural habits in writing letters was revealed by discrimination of the two sides.

INTRODUCTION

History of paper manufacturing began in ancient China. In East Asia, this technology was handed down to Korea at some time between the 2nd and 4th centuries according to an ancient Korean record1) and finally to Japan in 610 according to the Japanese oldest historiography. In these modern days, a lot of paper is industrially produced from wood pulp fibers, but paper materials for Korea and Japanese ancient art and documents was made of bast fibers. As for papermaking tools, following is the Japanese characteristic tools used nowadays2) and it seems that paper craftsmen have used similar tools with the same principle for hundreds of years. The forming screen (corresponding to the forming wire in the modern papermaking) is made of finely split and beveled bamboo splints woven together with silk threads, leaving faint characteristic "chain lines" in the finished sheets. A craftsman clamps the forming screen into the light wooden frame to use it as a mold. Korean and Japanese papers, called Hanji and Washi, respectively, in their own countries, might appear to be similar to each other. However, they have many different aspects nowadays and the differences date back to the medieval times or earlier.

From a viewpoint of the screen motion, traditional sheet forming processes are classified basically to two methods; the still-sheet forming method and the flow-sheet forming method. In the flow-sheet forming method, a mold is dipped into a vat containing fibers suspended in water. The filled mold is lifted above the water and then swished back and forth or sideways. Several dips of additional fibers and sloshes-off of the excess fibers form one sheet. This Asian unique method of sheet formation contrasts with the still-sheet forming method where the mold is dipped only once and allowed to drain naturally. The still-sheet forming is commonly used in the West and some areas of the East3).

Generally, fibers in a suspension flow tend to be oriented in the flow direction. The motion of the screen in the two methods of sheet forming is differently reflected in the fiber orientation of paper. Namely, fibers are likely to be oriented greatly by the flow-sheet forming, but hardly by the still-sheet forming. In order to evaluate the extent (anisotropy) and direction (angle) of fiber orientation objectively, a new nondestructive image analysis technique was developed and applied to micrographs of paper surfaces[4)]. If this principle is applied the other way round, Hanji and Washi manufactured in the past must show their characteristics to the fibers flow, namely, the screen motion at the time of sheet forming [5)]. Consequently, fiber orientation can be a criterion to classify ancient papers according to the sheet forming method. This application covers not only oriental papers but also western papers.

The purpose of this work is to estimate the sheet-forming methods used for manufacturing papers of historic documents and thus the papermaking technology in those days. In addition, we expect that this image analysis technique developed in this work will be utilized to select a repair paper that matches the original paper as a part of cultural properties by conservators.

EXPERIMENTAL

Image analysis for fiber orientation

Statistically, fiber alignment is expressed as a fiber orientation distribution as a function of angle. For the handmade papers analyzed in this work, the left and right direction of the squared mold from the craftsman's view is assumed to be 0 °. The major direction of fibers was determined following the next steps[4)]. First, a micrograph as a 256 gray level image was trimmed to a size of 1024 by 1024 pixels (Fig. 1(a), for example) for fast Fourier transform (FFT). Second, the images were binarized using a dynamic threshold method of image partition (Fig. 1(b)). This binarization process can correct the shading of images photographed under non-uniform illumination[6)]. FFT was computed with these binary images to obtain power spectra like Fig. 1(c) calculated from Fig. 1(b). The central bright region extending relatively in the horizontal direction in Fig. 1(c) relates to the fiber orientation. In the process of evaluating fiber orientation, amplitude (a square root of power) was added in the radius direction from the origin and its mean was determined for each angle from 0 to less than 180 ° above the horizontal-axis. If the mean amplitude values are plotted as a function of angle in the polar coordinates, fiber orientation diagrams like a curve drawn with the solid line in Fig. 1(d) is obtained. This curve was approximated to an ellipse drawn with the dotted line using another technique of FFT. The ellipse has the longer (L) and shorter (S) axes at right angles to each other. The angle of θ ($0 \leq \theta < 180$ °) and the magnitude of elongation calculated as length L divided by length S represents the direction and anisotropy of fiber orientation, respectively. In order to determine the overall fiber orientation for the identical sheet, the mean amplitude values of all the images within the sheet were accumulated for each angle and the overall orientation angle and anisotropy were calculated in the same manner as the procedure for a single image.

Samples

Contemporary handmade papers

Contemporary papers manufactured in the traditional methods in South Korea and Japan were examined. The samples used were Mino paper with a basis weight of 61 g/m^2 (symbol H, Washi) prepared by S. Hasegawa, Jangji of 57 g/m^2 and Uiryeong of 52 g/m^2 (symbols J and U, respectively, Hanji). Those samples have a mean thickness of 0.158, 0.143 and 0.141mm for samples H, J and U, respectively. These two kinds of Hanji were made at craft studios in the traditional papermaking districts Uiryeong and Jangji, Korea. Mino is a name of the city with a lot of Washi production.

Model papers hand-made in laboratory

Traditional sheet forming methods were simulated

1. Still-sheet forming: a mold is dipped into a fiber suspension once, lifted with the horizontal position kept and left still until the excess water has drained away.
2. Flow- and still-sheet forming: one operation of the flow-sheet forming followed by one operation of the still-sheet forming after a quick motion of mold dipping.
3. Flow-sheet forming: the craftsman's side edge of a mold is dipped into a fiber suspension once, lifted and slanted so an excess suspension flows out over the far side edge, and subsequently dipped into the fiber suspension once again, lifted, shaken back and forth for a short time and slanted so an excess suspension flows out again over the far side edge; after the removal of the dilute portion of the fiber suspension, the mold with the wet web remaining on the screen is returned to the horizontal position to complete the draining process.

The fiber suspension with a consistency of 0.5 % was prepared from mulberry fibers after beating to 1000 revolutions with a PFI mill. Two litters of a 0.09% solution of Neri extracted from lightly-hammered roots of Abelmoschus manihot immersed in water was added to 40 litters of the fiber suspension. Bamboo splints of the screen are 0.1 mm thick and woven at 28 pieces per Sun (30.3 mm).

Ancient document papers

Japanese ancient documents, — the Shimadzu Family documents — owned by the Historiographical Institute, University of Tokyo, were examined. The documents are correspondences exchanged between the Shogunate Government of Edo and the Shimadzu Family in Satsuma (currently, Kagoshima prefecture, Japan). The paper-made formal letters corresponded from the Shogunate Government (Edo era) ranging from 1606 to 1859 were selected for examination.

Korean ancient documents from the 11th to 16th centuries were examined. The documents include the Korean Buddhism sacred book and several ancient documents mainly in the Goryo Dynasty period and the Chosun Dynasty period conserved in HOAM museum or by an individual in Korea.

Daitokuji is a temple in Kyoto and conserves a lot of historic documents. The number of the analyzed Daitokuji document papers ranging from the 12th to 18th century was 106. The side was not distinguished between the screen side with the higher anisotropy and the top side with the lower anisotropy, but was distinguished between the written side and the non-written side. Formal letters using only one sheet for writing texts accompanies a blank sheet as a backing customarily.

Method of acquiring surface images

A digital microscope DG-2, Scholar Co. Ltd., Japan was used to acquire reflected light images of paper surfaces with a lens of 100 times magnification. For the contemporary handmade papers and the model papers hand-made in laboratory, five images were captured from each of the nine evenly spaced locations; these locations were horizontally located in groups of three along the top, middle, and bottom of a sheet. Images of 1024 × 1024 pixels corresponding to 1.66 × 1.66 mm^2 were subjected to FFT followed by the calculation of fiber orientation distribution. For ancient document papers, 10 images from evenly spaced 10 locations on either side of the ancient document papers were taken and subjected to the same processes of the image analysis.

For every image, the bottom side corresponds to the position from which the craftsman held the wooden frame with a bamboo wire. Therefore, a fiber orientation angle of 0 degrees, for example, is equivalent to the left-and-right direction from the craftsman's view. The ancient document books or papers were placed so that the writing direction comes to be vertical in the captured image.

RESULTS AND DISCUSSION

Analysis of contemporary handmade papers

Fig. 1 shows an example of the FFT image analysis for fiber orientation distribution of contemporary paper H. Photograph (a) is a representative micrograph of the sample. Its binary image (b) was subjected to FFT to calculate power spectrum (c). The diagram of overall fiber orientation (d) includes two drawings; the solid line shows a practical plot of the distribution and the dotted line shows its approximated ellipse with the longer axis in the horizontal direction. The direction of the shorter axis means the orientation angle. The shape of this ellipse shows a high anisotropy and the orientation angle is almost 90 °. Fig. 2(a) shows the anisotropy and orientation angle for the contemporary papers. For the screen side, all the samples give high anisotropies ranging from 1.16 to 1.22 and their orientation angles of all about 90 ° as Fig. 2(b) shows. For the top side, Washi H gives a fairy high anisotropy, while Hanji J and U show random fiber orientation as shown by the anisotropies almost equal to unity. The orientation angles for the top side corresponding to anisotropies less than 1.05 is not presented in this figure because such angles have no significance. The orientation angle of 90 ° means that the craftsman slanted the mold and let the fibers flow in the back-and-forth direction as he regularly does. The general tendency of our data about the two-

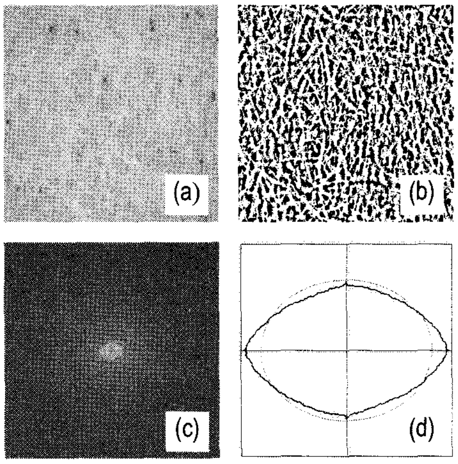

Fig. 1 Micrograph of screen side of Washi H with digital optical microscope (a), binary image (b), FFT spectrum (c) and distribution diagram of overall fiber orientation

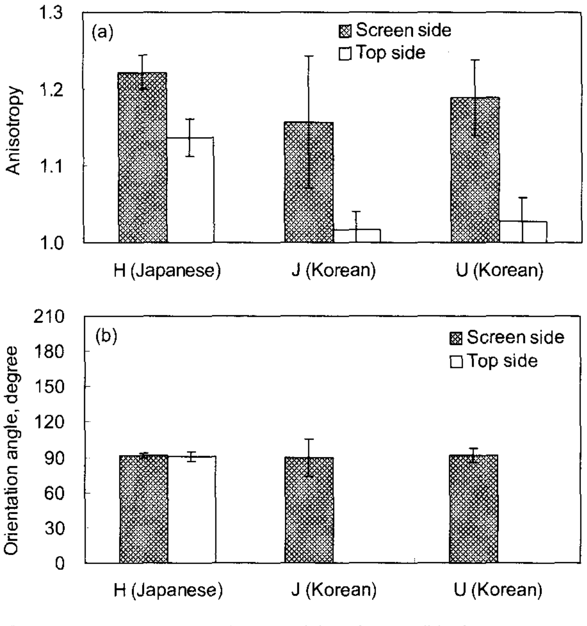

Fig. 2 Fiber orientation anisotropy (a) and angle (b) of Korean and Japanese contemporary papers. Error bars represent 95 % confidence intervals as in other figures.

sidedness is that the screen side always has higher anisotropies.

Analysis of model papers

To assure the relationship between the mold motion and fiber orientation, typical motions of the traditional sheet forming were simulated in laboratory. Fig. 3(a) and (b) show the anisotropy and orientation angle of the model papers. The flow-sheet forming method shows the highest anisotropy and the still-sheet forming shows the lowest anisotropy as we expected. Approximately, anisotropies higher than 1.10 and those lower than 1.05 mean strong fiber orientation and random fiber orientation, respectively. The sequential flow- and still-sheet forming method brought about fairly high anisotropy for the screen side and very low anisotropy, that is, the random orientation for the top side. This result agreed reasonably with the relationship that can be predicted from the screen motion. The significant two-sidedness was observed with the model paper prepared by the flow-sheet forming method. This paper consists of two layers formed by twice flow-sheet forming actions. The degree of anisotropy is related to the dehydration rate. The first layer of a fiber mat is formed usually during quick dehydration and ends of fibers are easily trapped by the bamboo splints of the forming screen with the fibers easily oriented. But, this first layer reduces the dehydration rate of the second fiber suspension. Therefore, when the excess of the second fiber suspension is made to flow out, fibers are hardly retained because of few trapping chances.

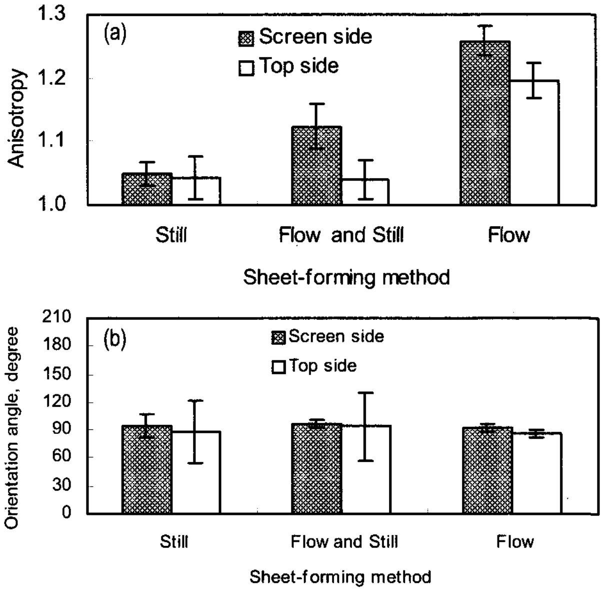

Fig. 3 Fiber orientation anisotropy (a) and angle (b) of model papers hand-made in laboratory by three different methods of sheet forming.

Analysis of ancient document papers

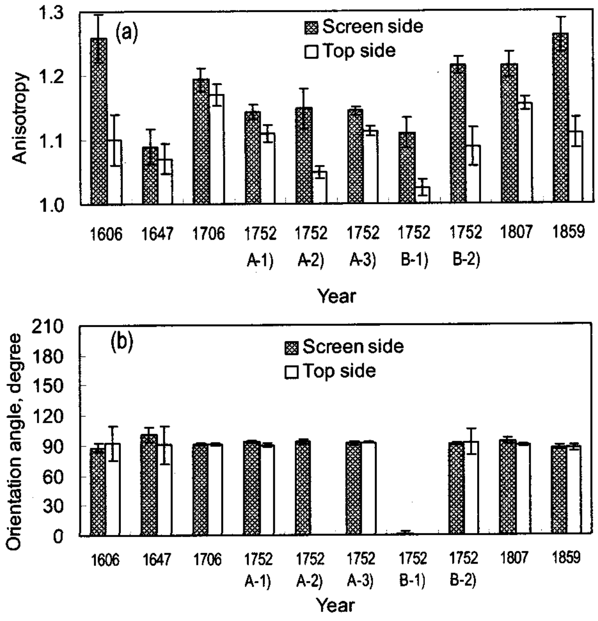

Fig. 4 Fiber orientation anisotropy (a) and angle (b) of Japanese ancient documents (Shimadzu). Sample1752 B-1) is only envelope sheet and the rest are all letter papers for texts or blank.

Shimadzu Family documents

Fig. 4(a) and (b) shows the results for the Shimadzu Family documents. Anisotropy of the screen side was higher than or almost equal to 1.10 for every sample. The 1752 B-1) paper showed a relatively low anisotropy of 1.11. Only this paper was used for wrapping as an envelope sheet, though all the others were main letter papers or the same kind of blank sheets (ancient official letters always consist of two sheets). The orientation angle was all about 90 ° with an exception of 0 ° for the screen side of the envelope sheet. This is because the envelope sheet was used customarily with a lateral side up, namely, after rotation of 90 °. It was found that the fiber orientation analysis can be used to confirm this custom when there is no evidenced directionality recognized with ease from the appearance of the paper. The orientation angles for the top side corresponding to anisotropies less than 1.05 are not presented because of random orientation.

Korean ancient documents

Fig. 5(a) and (b) shows the results for the Korean ancient documents. The anisotropy and angle of fiber orientation was separately calculated for the written and non-written sides, respectively, unlike the calculations made for the other samples so far. The samples in the mid 14th century had a higher anisotropy for the written side than for the non-written side. This fact means that the screen side was mainly selected for writing. However, most samples show no significant difference between the written and non-written sides. Basically, Korean papers had not had the distinctive two-sidedness regarding comfortable writing. This may be derived from still-sheet forming typical of Korean paper. Regarding the orientation angle, there were two angles calculated — 0 ° and 90 ° (about 180 ° is almost equal to 0 °). These two angles were not systematically distinguished from the written side to the non-written side. However, this tendency contrasts with that of Japanese paper with the orientation angle indeed mostly of 90 ° regardless of what kind of two-sidedness.

Fig. 6 shows a result for the Daitokuji document papers. By the typical, but non-systematic classification method from viewpoints of such as fiber sources, presence of additives like rice powder (if present, it is called "suibara") and presence of a striped-wrinkle pattern ("hikiawase"), papers manufactured in the medieval times can be sorted as shown in this figure. However, there is no significance with the order of the paper category names or the data plot order in each paper category. In most samples and most paper categories, the written side had higher anisotropy. This fact means that the screen side was selected for writing because every formed wet sheet is spread over a wooden drying board usually with the screen side in contact with the board surface and the screen side becomes smoother than the top side. But, the Shukushi papers showed the opposite result. Shukushi means recycled paper and has a remarkable screen mark with dark lines where residual Indian ink particles collected. This is the reason why writers avoided the screen side of Shukushi for brushstrokes. The fiber orientation analysis helped to know that it was the screen side with the higher anisotropy that had a screen mark and that ancient writers used the top side for writing in spite of the rough side.

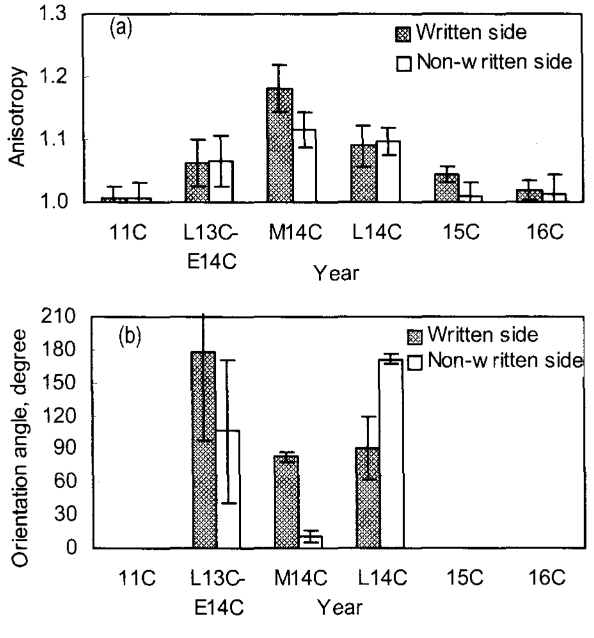

Fig. 5 Fiber orientation intensity (a) and angle (b) of Korean ancient documents. In symbols, L, M and E denotes "late", "mid" and "early", respectively.

As is mentioned earlier, Japanese writers of letters have customarily used two sheets if the second sheet was blank. For such double sheet letters, two sheets were first taken together from a paper stack where sheets were stacked all with the smooth side face up. Text started to be written usually on the smooth side of the first sheet. Then, the two sheets together were turned over to go to the second page if necessary. Table 1 shows the fiber orientation anisotropy of the two sides of the two each sheet as well as the estimated situation how the sheets of the double sheet letters in the Daitokuji document were handled for writing. The regular pattern is that the written side of the first sheet and the unwritten side of the second sheet is the smoother side, that is, the side contacting a wooden drying board (traces of annual rings were observed on this side and the figure of anisotropy is denoted by "Brd" in the table). This regular pattern was observed with 15 letters with the exception of 3 letters as denoted by "One upside down". Concerning the drying process, the screen side is regularly in concordance with the "Brd" side, but the discordance was observed with 6 letters (247-1, 469-1, 535-1, 788-1, 1509-1 and 1543-1). The result of the fiber orientation analysis revealed that such a reverse drying — the top side attached on a wooden drying board — was not too exceptional.

CONCLUSIONS

A nondestructive method of image analysis using fast Fourier transform has been developed to analyze anisotropy and angle of fiber orientation of paper surfaces. When this method was applied to contemporary Korean and Japanese papers, they showed their own characteristics in accordance with the motion of a papermaking screen. Anisotropy of fiber orientation was found to be higher for flow-sheet forming and lower for still-sheet forming as a result of anisotropy of model papers hand-made in laboratory. Moreover, the anisotropy was always higher for the screen side than for the top side, thus meaning that surface fiber orientation is possible to distinguish the two sides of paper of which papermaking history is unknown. An application of this technique to actual historical documents evidenced that wrapping papers were used as envelops with a lateral side up, namely, after rotating 90 degrees. A variety of cultural habits in writing letters was revealed by discrimination of the two sides.

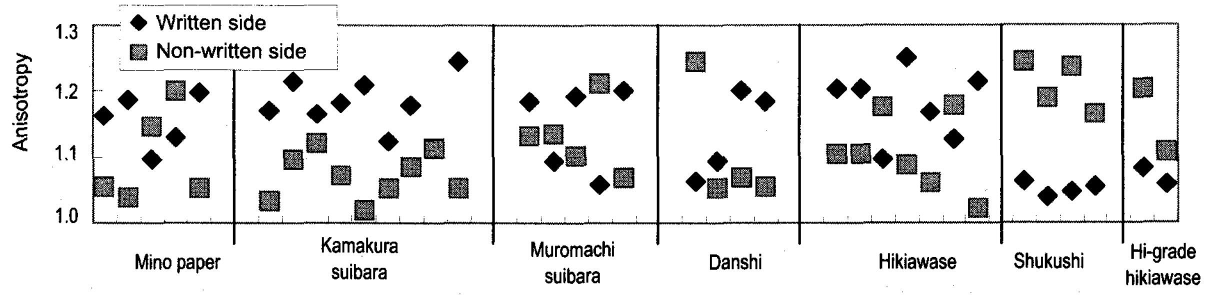

Fig. 6 Anisotropies of Daitokuji document papers classified under papermaking processes and additives etc..

Table 1 Fiber orientation anisotropy of first and second sheets comprising double sheet letters in Daitokuji document

Doc #	First sheet		Second sheet		Pick-up pattern of double sheets
	Written side	Non-written side	Non-written side	Written side	
174	**1.20Brd**	1.04Brsh	**1.18Brd**	1.08Brsh	Together
196	**1.28Brd**	1.12Brsh	**1.26Brd**	1.17Brsh	Together
205	**1.19Brd**	1.15Brsh	**1.10Brd**	1.05Brsh	Together
206	**1.22Brd**	1.08Brsh	**1.19Brd**	1.10Brsh	Together
224	**1.19Brd**	1.12Brsh	**1.22Brd**	1.13Brsh	Together
247-1	1.14Brd	**1.20Brsh**	1.16Brd	**1.19Brsh**	Together
253	**1.15Brd**	1.06Brsh	**1.16Brd**	1.06Brsh	Together
293	**1.19Brd**	1.08Brsh	**1.21Brd**	1.10Brsh	Together
419-1	**1.21Brd**	1.12Brsh	**1.21Brd**	1.13Brsh	Together
469-1	1.07Brd	**1.26Brsh**	**1.28Brd**	1.09?	Together*
535-1	1.09?	**1.19?**	**1.25?**	1.10Line	Together*
549-1	**1.31Brd**	1.15Brsh	**1.33Brd**	1.11Brsh	Together
566-1	**1.24Brd**	1.13Brsh	**1.23Brd**	1.15Brsh	Together
593-1	**1.21?**	1.09?	**1.27?**	1.10?	(Together)
788-1	**1.22?**	1.17Brsh	**1.17Brsh**	1.09?	One upside down*
1509-1	**1.19Brd**	1.14Brsh	**1.22Brsh**	1.12Brd	One upside down*
1543-1	1.06Brd	**1.22?**	**1.19?**	1.07?	Together*
1557-1	**1.19Line**	1.10Brsh	**1.16?**	1.06Line	One upside down*

"Brd", the side contacting drying board; "Brsh", the side brushed for spread; "Line", thick lines found but side unknown; "?", side unknown; **Bold** font, the side with higher anisotropy (screen side); "Together", two sheets taken together from stack; " One upside down", one of two sheets turned upside down; "*", discordance between screen side and Brd side.

REFERENCE

1) Jung, S.-Y., A study on the introduction of paper and papermaking technique in ancient Korea, PhD dissertation, Yonsei University (1997) [in Korean].

2) Sukey, H., Washi the world of Japanese paper, 99, Kodansha International (1978).

3) Glossary chapter, Text book of "International course on conservation of Japanese paper 2002", 123, National research institute for cultural properties Tokyo (2003).

4) Enomae, T., Han, Y.-H. and Isogai, A., Nondestructive determination of fiber orientation distribution of paper surface by image analysis, Nordic Pulp Paper Res J, 21(2), in press (2006).

5) Han, Y.-H., Enomae, T., Isogai, A., Yamamoto, H., Hasegawa, S., Song J.-J., and Jang, S.-W, Comparison of traditional hand papermaking techniques in the Japanese (Washi) and Korean (Hanji) traditions, with particular reference to the study of fiber orientation in historical and contemporary papers", Studies in conservation, in press

6) Murata, K. and Fujita, M., FFT-estimation of fiber orientation on wood fiberboard, J. Soc Mat Sci 48(1): 77(1999)