Traditional Papermaking Techniques revealed by Fibre Orientation in Historical Papers

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This work aims to select adequate repair papers, based on fibre orientation information derived from paper objects during restoration, using non-destructive image analysis applied to micrographs of paper surfaces. Contemporary Japanese handmade papers exhibited high values of fibre orientation intensity, while contemporary Korean handmade papers exhibited low intensity values. This difference was assumed to be due to different sheet-forming actions. Model papers prepared in the laboratory by the still sheet-forming and flow sheet-forming methods had low and high values of fibre orientation intensity, respectively. Additionally, the screen side for the flow sheet-forming method had a value of fibre orientation intensity higher than the top side. This fact was logically explained in terms of fibre flow and dehydration rate, and consequently suggests its applicability to distinguishing the sides of ancient document papers. The application of this technique to the Shimadzu Family documents from 1606 to 1859 indicated high values of fibre orientation, suggesting that the flow sheet-forming method had already been established by the early seventeenth century in Japan. The papers of Korean Buddhist sacred books manufactured between the eleventh and sixteenth centuries exhibited low orientation intensity values, and the differences between the two sides were small. This indicates that the papers were manufactured by the still sheet-forming method concurrently with a sideways swing.

INTRODUCTION

Paper manufacturing began in ancient China. In East Asia, this technology passed first to Korea some time between the second and fourth centuries CE according to an ancient Korean record [1] and then to Japan in 610 CE according to the *Chronicle of Japan*. Although much modern paper is industrially produced from wood pulp fibres, the paper materials for ancient Korean and Japanese art and documents were made of bast fibres (*Cannabis sativa* L., *Boehmeria nivea* Gad., *Broussonetia kazinoki* Sieb., etc.) as are contemporary handmade papers that are manufactured in the traditional ways.

Some of the traditional hand-making technologies of paper practised for generations are still alive in today's Korea and Japan, using traditional fibre sources. The structure and functions of papermaking tools have been maintained without revolutionary changes except in the accuracy of their construction. The following traditional Japanese characteristic tools are still in use. The forming screen, called a *Su* (corresponding to the forming wire in modern papermaking), is made of finely split and bevelled bamboo splints woven together with silk threads. In some areas, miscanthus and other reeds woven with horsehair are used, leaving faint characteristic 'chain lines' (*Itome*) in the finished sheets. The screen is highly flexible, rigid on the weft and pliant on the warp, rather like a huge, finely crafted bamboo place mat. A craftsman clamps the forming screen into the light wooden frame equipped with copper hinges and catches. This frame, called a *Keta*, has two handles on top, spaced for the craftsman to grasp comfortably. The screen (*Su*) is secured into the frame (*Keta*), to create a rigid mould called a *Sugeta* [2].

Korean and Japanese papers, called *Hanji* and *Washi*, respectively, in their own countries, appear to be similar to each other. However, they are now known to have many different aspects. In addition to current techniques, literature written in medieval and modern times regarding hand-making methods tells us that *Hanji* and *Washi*, and many of their respective characteristic techniques which form the roots of modern practice, were historically developed in different manners with regard to papermaking technology.

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Traditional sheet-forming processes used in the manufacture of *Hanji* and *Washi* are classified into two methods, depending on the screen motion: the still sheet-forming method (*Gadumtugi* in Korean and *Tamezuki* in Japanese) and the flow sheet-forming method (*Hulrimtugi* in Korean and *Nagashizuki* in Japanese). These two methods still remain the major hand-making paper technologies. In the flow sheet-forming method, a mould is dipped into a vat containing beaten fibres suspended in water with some amount of a viscous substance called *Neri* to disperse fibres for good sheet formation. The filled mould is lifted above the water and then moved back and forth or sideways, so the sheet becomes homogenized and excess fibres are thrown off. Several dips form one sheet, which is then transferred to a pile of paper to be pressed together. This unique Asian method of sheet formation contrasts with the still sheet-forming method where the mould is dipped only once for each sheet. Still sheet forming is commonly used in the West and some areas of the East [3].

The motion of the screen in the two methods of sheet forming described above is reflected in the fibre orientation of the paper. If one observes the surface of a traditional handmade paper, even with just a simple magnifier, one can often easily find fibres running in a specific direction. However, it is impossible to evaluate the extent (intensity) of fibre orientation or the exact direction (angle) of the orientation comprehensively and objectively by visual inspection alone. An image analysis technique, such as a scientific method using micrographs [4], allows one to quantify the intensity and angle of fibre orientation of paper surfaces non-destructively. *Hanji* and *Washi* manufactured in the past must show characteristic fibre flow, related to the screen motion at the time of papermaking. Consequently, fibre orientation can be used as a criterion to classify ancient papers according to the sheet-forming method.

Recently, many ancient documents and historical papers have been restored using repair papers, most of which are Japanese and Korean, which were chosen for their compatibility with the original paper under restoration. In selecting appropriate repair papers, fibre orientation is one of the important factors, as it affects the shrinkage and curl of the restored paper over a period of time. Incompatible fibre orientation between original and repair papers might damage and spoil the important original paper several years after restoration.

The purpose of this work is to characterize the sheet-forming methods and technology used for manufacturing papers of historic documents. In addition, it is anticipated that the image analysis technique developed in this work can be utilized in selecting repair papers appropriate for the treatment of original paper objects by conservators. This technique is applicable not only to oriental papers but also to western papers.

EXPERIMENTAL

Image analysis for fibre orientation

Statistically, fibre alignment is expressed as a fibre orientation distribution as a function of angle. As a consequence of the statistical calculation, the fibre orientation angle is defined as the major angle which the largest number of fibres or fibre segments take. The fibre orientation intensity is defined as the degree of concentration of the orientation. For the handmade papers analysed in this work, the left and right direction of the squared mould from the craftsman's view is assumed to be 0°.

The major direction of fibres was determined as follows [5]. First, a micrograph as a 256 grey-level image was trimmed to a size of 1024×1024 pixels (Figure 1a, for example) to facilitate the fast Fourier transform (FFT) computation. Second, the images were binarized using a dynamic threshold method of image partition (Figure 1b). This binarization process is not always necessary, but can correct the shading of images photographed under non-uniform illumination, which can frequently obscure the measurement of true fibre orientation. Additionally, this binarization process can resolve the edges of out-of-focus fibres located below the plane of focus of the micrograph [6]. FFT was computed with these binary images to obtain power spectra like that shown in Figure 1c, which was calculated from Figure 1b. The central bright region and its horizontal extension relate to the fibre orientation.

To evaluate fibre 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, fibre orientation diagrams like the curve drawn with the thicker line in Figure 1d are obtained. The property of point symmetry, with respect to the origin, facilitates the data plot in the region below the horizontal axis. The elliptical curve drawn with the thinner line uses another technique of FFT. The ellipse has longer (L) and shorter (S) axes at right angles to each other. The angle of S ($0 \leq S < 180°$) represents the direction of fibre orientation. The magnitude of elongation, calculated as length L divided by length S,

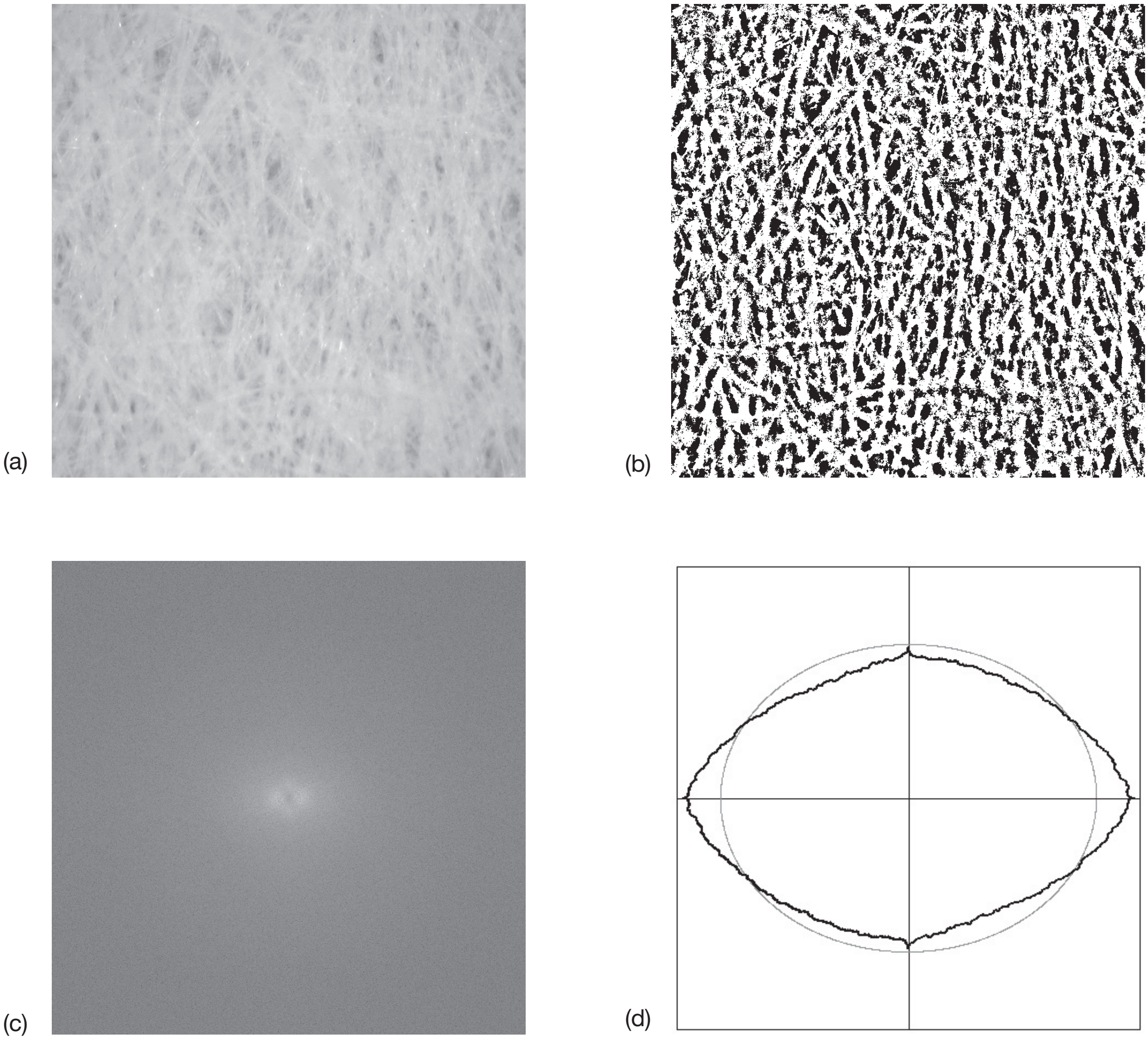

Figure 1 Micrograph of the screen side of Washi *H: (a) with digital optical microscope, (b) binary image, (c) FFT spectrum and (d) the distribution diagram of overall fibre orientation.*

represents the intensity of fibre orientation. In order to determine the overall fibre orientation for a given sheet, the mean amplitude values of all the images were accumulated for each angle, and the overall orientation angle and intensity were calculated in the same manner as the procedure for a single image. For determining the deviation among images of the same type of sample, a standard deviation was calculated from individual values of the orientation angle and intensity for every image.

Samples

Contemporary papers manufactured using traditional methods in South Korea and Japan were first examined to determine fibre orientation. The samples used were Mino paper with a basis weight of 61 $g{\cdot}m^{-2}$ (*Washi* H) prepared by S. Hasegawa, Jangji of 57 $g{\cdot}m^{-2}$ (*Hanji* J) and Uiryeong of 52 $g{\cdot}m^{-2}$ (*Hanji* U). The samples had mean thicknesses of 0.158, 0.143 and 0.141 mm, respectively.

The two types of *Hanji* were made at studios based in the traditional papermaking districts of Uiryeong and Jangji, Korea. Mino paper is one of the major *Washi* products, and it is used mainly for the panels of sliding doors and the restoration of paper objects.

Handmade papers were prepared in the laboratory by the three methods described below, which simulate traditional sheet-forming methods:

1. Still sheet forming: a mould was dipped into a fibre suspension once, kept horizontal while lifting, and kept still until all excess water had drained away.
2. Sequential 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 mould dipping.
3. Flow sheet forming: the craftsman's side edge of a mould was dipped into a fibre suspension once, lifted and slanted so the excess suspension flows out over the far side, and subsequently dipped into the fibre suspension once again, lifted, shaken back and forth for a short time and slanted so the excess suspension flows out again over the far side. After the removal of the dilute portion of the fibre suspension, the mould with the wet web remaining on the screen was returned to the horizontal position in order to complete the draining process.

The fibre suspension with a consistency of 0.5% was prepared from mulberry fibres after beating for 1000 revolutions with a PFI mill. The PFI mill, a standard beater for paper testing [7], is composed of a roll with 33 bars arranged radially and a beater housing with a cover. During a beating operation, the roll and the housing rotate on vertical shafts in opposite directions as the bars are pressed against fibres distributed evenly on the inner wall of the beater housing. 2 L of a 0.09% solution of *Neri* extracted from lightly hammered roots of *Abelmoschus manihot* immersed in water was added to 40 L of the fibre suspension. The bamboo splints of the screen are 0.1 mm thick and woven at 28 pieces per *Sun* (30.3 mm). The papers prepared in this way are referred to as the model papers in the following sections.

In addition, ancient Japanese documents owned by the Historiographical Institute, University of Tokyo, were examined as actual samples for application of this technique. These documents included the correspondence sent between the Shogunate Government of Edo and the Shimadzu Family in Satsuma (currently, Kagoshima prefecture, Japan). Formal letters comprising correspondence from the Shogunate Government (Edo era), ranging from 1606 to 1859, were selected as Japanese documents for examination. A selection of Korean documents from the eleventh to sixteenth centuries was also treated. These included the Korean Buddhist sacred book and several ancient documents mainly from the Goryo Dynasty and Chosun Dynasty periods conserved as important cultural assets.

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 100× magnification lens. Specimens were illuminated on a scanning stage at a low angle. Individual images were 1792 × 1184 pixels in size, but the central areas (1024 × 1024 pixels region corresponding to 1.66 × 1.66 mm) were subjected to FFT followed by calculation of fibre orientation distribution.

The repair paper samples H, J and U were photographed with this digital microscope at two locations about 100 mm apart within a sheet. Five micrographs were taken at each location and subjected to image analysis. When micrographs were taken, every paper sample was placed so that the edge closest to the papermaker (during making) or the opposite edge came to the bottom of the image.

As for the model papers, one representative sheet was selected from the three kinds of paper. Five images were captured from each of nine evenly spaced locations at the top, middle and bottom of the left, centre and right of a sheet. With the ancient documents, ten images each of the screen sides and top sides were analysed. The micrograph specifications were the same as those for the repair papers.

RESULTS AND DISCUSSION

Analysis of model handmade papers and contemporary repair papers

Figure 1 shows an example of the FFT image analysis for fibre orientation distribution of repair paper H. The photograph (a) is a microscope image of the sample. Its binary image (b) is formed by the dynamic threshold method. Then, FFT is applied to the binary image to give the two-dimensional power spectrum (c). Finally, angle-by-angle mean amplitude values of all the images at different locations of the same sample are accumulated to obtain the overall fibre orientation (d). The micrograph (a) was selected so that the calculated values of fibre orientation would come closest to the overall ones. The diagram of overall fibre orientation (d) includes two curves; one is a practical plot of the distribution and the other is its approximated ellipse with the longer axis in the horizontal direction. As explained in the Experimental section, the direction of the shorter axis represents the orientation angle. In this case, the fibre orientation is very intense and the orientation angle is almost 90°. In contrast, the distribution diagram of *Hanji* J (Figure 2d) is relatively isotropic, indicating that there is no specified angle of fibre orientation. Accordingly, the fibre orientation intensity is as low as 1.02.

Figure 3 shows the intensity and angle of fibre orientation for the three kinds of contemporary repair papers. For the screen side, all the samples give high values of orientation intensity ranging from 1.16 to 1.22 and orientation angles of about 90°. For the top side, *Washi* H gives a fairly high value of orientation intensity, while *Hanji* J and U show no fibre orientation because the intensity values are almost equal to unity. The corresponding orientation angle of *Washi* H is about 90°, although those of *Hanji* J and U have very large 95% confidence intervals, denoted by the symmetrical error on the top of each thick bar in the figure. 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 intensity 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 fibre orientation intensity indicating that the screen side always has higher intensity values. The relationship between the mould motion and fibre orientation was reconsidered carefully, not only by observing how a craftsman operates the mould but also by preparing handmade paper in the laboratory by simulating typical motions of the traditional sheet formation. Fibre orientation was examined with the model papers. Figure 4 shows the intensity and angle of fibre 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 fibre orientation, and the still sheet-forming method shows the lowest value (< 1.10), indicating random fibre distribution. The sequential flow and still sheet-forming method has intermediate intensity values for the screen side, and the random orientation of the top side is as expected from the low intensity value.

A marked difference between the two sides was observed with the model paper prepared by the flow sheet-forming method as well as with repair paper H. Both of these papers were prepared by two flow sheet-forming actions. Considering that the flow speed is not likely to be obviously different, the difference in the fibre orientation intensity between the first and second fibre mats can be explained in the following way. Fibres in a fast-flowing suspension tend to be orientated in the flow direction, but if dehydration is slow, the orientated fibres are not retained on the fibre mat. The first layer of a fibre mat is usually formed during fast dehydration, because the gaps between the bamboo splints of the forming screen are sufficiently wide, and the first layer on the screen shows high orientation intensity values. But this first layer reduces the dehydration rate of the second fibre suspension, and consequently the craftsman must keep the suspension for a longer time than for the first layer, shaking the mould to avoid unacceptable fibre aggregation. During this stage, the second layer is formed by random sedimentation of fibres. When the forming process approaches completion, the excess suspension is made to flow out, and hardly any fibres are retained from this suspension because of slow dehydration. This is probably the reason why the top side shows the lower intensity value of fibre orientation for the sequential flow and still sheet-forming method. The model papers prepared for this study do not have good formation, with fibre aggregates scattered over the whole area. They appear to be inferior to the products of professional craftsmen, but the results appear consistent with the formation process.

Application of the image analysis to ancient document papers

Figure 5 shows the results of fibre orientation for the Shimadzu Family documents. Fibre orientation intensities of the screen side resulted in values higher than or almost equal to 1.10 for most of the manufacture years. The 1752 (B-1) paper showed a relatively low intensity value of 1.11. This paper was used for wrapping as an envelope sheet, and all the others were letter paper or the same kind of blank sheets of paper (two or more sheets are necessary for letters by Japanese etiquette). The orientation angles were all about 90° with the exception of 0° for the envelope sheet. This is because the envelope sheet was customarily rotated through 90° before use. The top side was expected to show about 0°, but, it showed about 90° for the following reason. When

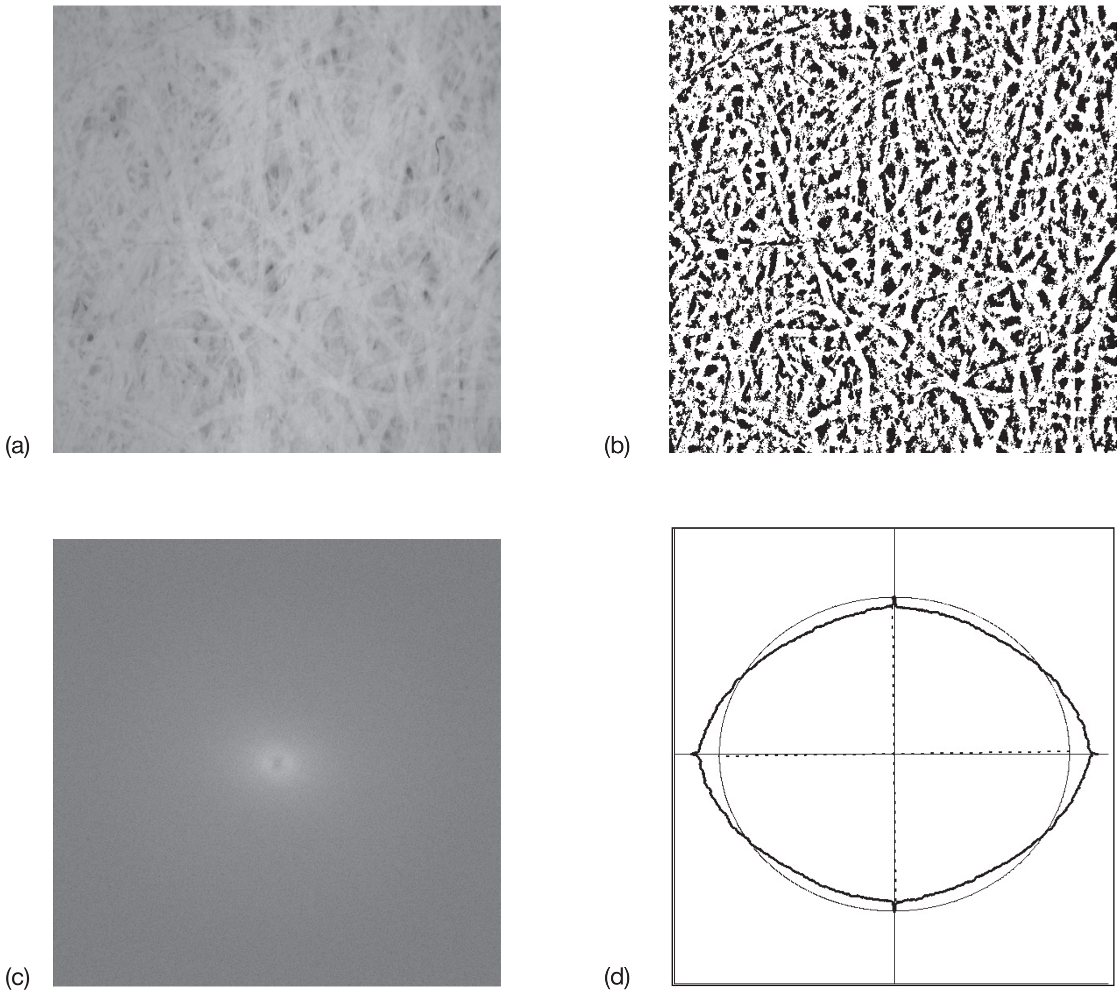

Figure 2 *Micrograph of the screen side of* Hanji *J: (a) with digital optical microscope, (b) binary image, (c) FFT spectrum and (d) the distribution diagram of overall fibre orientation.*

a Fourier transform is applied to a limited number of data points the orientation angle tends to be 0 or 90° for very low values of orientation intensity. Thus, in the case of low orientation intensity the orientation degree should be ignored. The top side shows lower values of orientation intensity over the whole range of manufacture years, as is typical of the flow sheet forming. This result therefore suggests that the flow sheet-forming method had already been established by the early seventeenth century.

Figure 6 shows the fibre orientation intensity and angle for the ancient Korean documents. The intensity and angle of fibre orientation was separately calculated for the written and non-written sides, unlike the calculations made for the other samples so far. The samples from the mid-fourteenth 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 did not have the distinctive two-sidedness regarding comfortable writing. This may be derived from the still sheet-forming method typical of Korean paper. Although the sideways screen

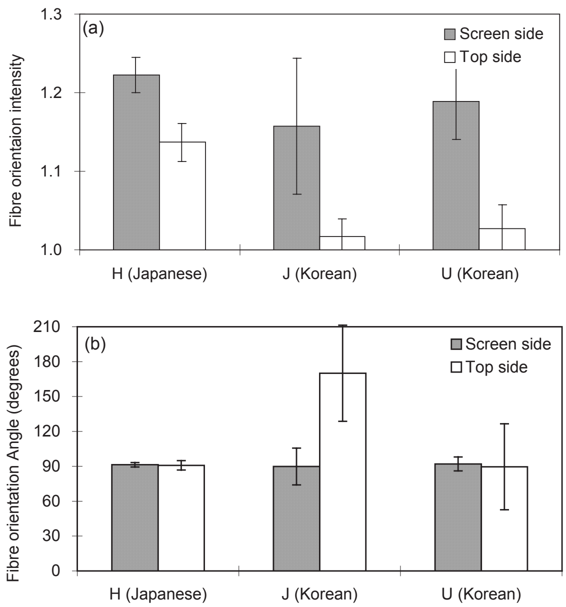

Figure 3 *Korean and Japanese repair papers: (a) fibre orientation intensity and (b) fibre orientation angle.*

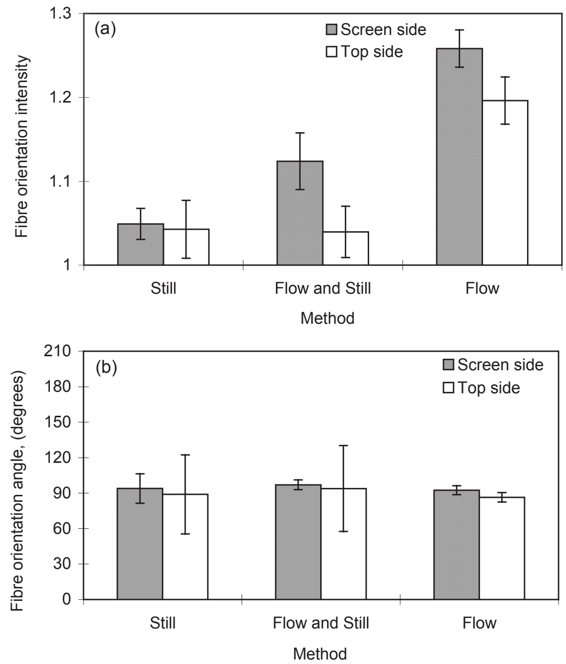

Figure 4 *Laboratory handmade papers prepared by three different methods of sheet forming: (a) fibre orientation intensity and (b) fibre orientation angle.*

swing had been introduced into Korean traditional sheet-forming processes by this period, according to the general historic view, this action does not seem to be reflected in the fibre orientation. One more important observation is that the difference in orientation intensity between the two sides is smaller than for the ancient Japanese documents. This observation is likely to correspond to the 'two-ply sheet structure', characteristic of Korea. Two plies, formed separately, are superimposed, with contact between the top side of the second ply and the screen side of the first ply in the opposite direction (the second ply is rotated through 180°) in the finished sheet of paper. Even if the difference in orientation intensity between the two sides of each ply is large enough, each ply has a thinner layer of orientated fibres in its surface than a single-ply sheet and randomly orientated underlying fibres photographed with the orientated fibres reduce the orientation intensity of the finished sheet. The technique of two-ply sheet forming is intended to counterbalance the inhomogeneous sheet structure in the longer direction, (i.e. between the back and front of the frame from the viewpoint of the craftsman) [8]. The lack of homogeneity is caused by the sideways swing used to make excess fibres flow out around the suspending point on the far side of the frame. Figure 7 depicts differences between hand-making moulds and equipment in the two countries. Two-ply sheet forming is also necessary to avoid the collapse of accumulated sheets for the following stage of wet-pressing. Moreover, the two plies are formed on the different sides of the same screen. This reverse action is used to wash out residual fibres that become lodged in gaps between the bamboo splints, and is customarily performed both in Japan and Korea.

CONCLUSION

Non-destructive image analysis, when applied to micrographs of paper surfaces using Fourier transform computation, elucidated the intensity of fibre orientation. For contemporary repair paper, the Japanese handmade paper showed a high value of fibre orientation intensity, while Korean handmade papers showed low values. This difference was assumed to be due to different motions of the papermaker's mould in sheet forming. For model papers prepared by the still and flow

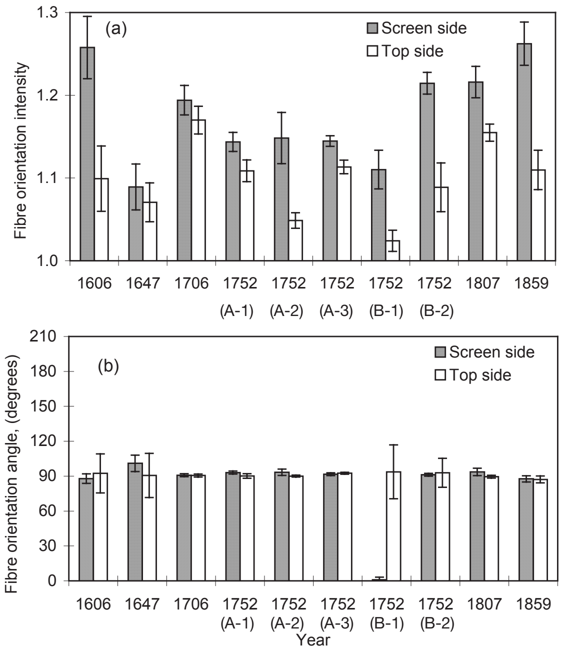

Figure 5 *Japanese ancient documents (Shimadzu): (a) fibre orientation intensity and (b) fibre orientation angle. For 1752, two documents A and B including the envelope sheet B-1 were examined.*

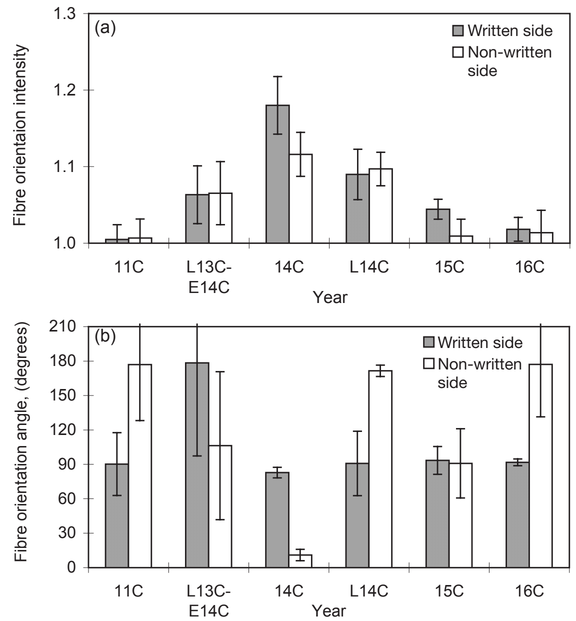

Figure 6 *Korean ancient documents: (a) fibre orientation intensity and (b) fibre orientation angle. L denotes 'late', and E 'early'.*

Figure 7 *Japanese* Yoshino *(left) and Korean* Jangji *(right) hand-making operations with characteristic tools.*

sheet-forming methods, the still sheet-forming method provided low values of fibre orientation intensity and the flow sheet-forming method provided high values. Additionally, it was found that the screen side showed a higher value of fibre orientation intensity than the top side for the repair papers, and for the model papers formed by the flow sheet-forming method. This is logically explained by the fibre flow and quick dehydration of the first layer providing high fibre orientation intensity, while slow dehydration prevents fibre orientation for the second layer. This observation can be used to distinguish between the sides of ancient document paper. The Shimadzu Family documents from 1606 to 1859 examined with this technique exhibited high values of fibre orientation, indicating that the flow sheet-forming method had already been established by the early seventeenth century in Japan. The papers of Korean Buddhist sacred books manufactured between the eleventh and sixteenth centuries exhibited low orientation intensity values, and the differences between the two sides were small. This indicates that these papers were manufactured by the still sheet-forming method basically and had the two-ply sheet structure.

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Résumé — *Ce travail vise à sélectionner des papiers pour la restauration en se basant sur l'orientation des fibres d'objets en papier faisant l'objet d'une restauration, en ayant recours à l'analyse d'image non destructive appliquées à des microphotographies de la surface du papier. Des papiers japonais contemporains fabriqués à la main montraient des valeurs élevées d'intensité d'orientation de fibres, alors que des papiers coréens contemporains fabriqués à la main donnaient des valeurs basses. La différence a été attribuée à différents processus de formation des feuilles. Des papiers modèles, préparés en laboratoire par des méthodes de formation statique ou dynamique des feuilles, ont donné respectivement des valeurs basses et des valeurs élevées d'intensité d'orientation des fibres. De plus, dans le cas de la méthode dynamique, la face de la feuille du côté du tamis donnait une valeur d'intensité d'orientation plus haute que l'autre face. Ce fait peut s'expliquer logiquement en termes de mouvement des fibres et de vitesse de déshydratation, ce qui suggère en conséquence une application possible pour distinguer les faces des documents anciens en papier. L'application de cette technique aux documents de la famille Shimadzu datant de 1606 à 1859 a donné des valeurs élevées d'orientation des fibres, ce qui tend à montrer que la méthode de formation dynamique avait déjà été mise au point dès le début du XVII^{e} siècle au Japon. Les papiers de livres sacrés coréens bouddhistes fabriqués entre le XI^{e} et le XVI^{e} siècle ont donné des valeurs d'orientation basses, et les différences entre les valeurs obtenues pour les deux faces du papier étaient faibles. Ceci indique que les papiers ont été fabriqués par la méthode statique tout en imprimant un mouvement latéral.*

Zusammenfassung — *Die vorliegende Arbeit bezweckt, Papiere adäquat auszubessern, indem während der Restaurierung anhand einer auf Mikrofotographien von Papieroberflächen basierenden, zerstörungsfreien Bildanalyse Informationen über die Faserorientierung gewonnen werden. Heutiges handgemachtes Papier aus Japan zeigt einen hohen Grad an Faserausrichtung, während zeitgenössisches Papier aus Korea geringere Werte aufweist. Es wird angenommen, dass dieser Unterschied auf verschiedenen Prozessen bei der Blattherstellung beruht. Im Labor hergestellte Modellpapiere zeigten eine niedrige Faserorientierung wenn sie nach dem Prozeß mit geringen Bewegungen geschöpft worden waren (einfaches Handschöpfen) und eine hohe bei Herstellung nach dem Prozeß mit heftigen Bewegungen (Handschöpfen nach traditionell japanischen Verfahren). Darüber hinaus hatte die Siebseite beim Prozeß mit geringen Bewegungen einen höheren Grad an Faserorientierung als die Oberseite. Diese Tatsache kann anhand des Faserflusses und der Trocknungsrate erklärt werden und erlaubt die Unterscheidung der verschiedenen Seiten bei historischem Papier. Die Anwendung dieser Untersuchungstechnik bei Dokumenten der Shimadzu Familie, aus der Zeit zwischen 1606 und 1859 erwies einen hohen Grad der Faserorientierung, was nahe legt, dass der Prozeß mit heftigen Bewegungen schon im frühen 17. Jahrhundert in Japan etabliert war. Die Papiere heiliger Bücher aus Korea aus der Zeit zwischen dem 11. und 16. Jahrhundert zeigten eine geringe Faserorientierung und nur kleine Unterschiede zwischen beiden Seiten. Dies legt nahe, dass die Papiere im Prozeß mit geringen Bewegungen geschöpft worden waren gleichzeitig mit einem Seitwärtsschwung.*

Resumen — *Este trabajo pretende seleccionar los tipos de reparación de papel más adecuados, basándose en la información aportada por la orientación de las fibras, obtenida a partir de objetos de papel sujetos a restauración utilizándose análisis por imagen no destructivos aplicados a micrografías de la superficie de los papeles. Los papeles japoneses contemporáneos hechos a mano mostraron altos valores en la intensidad de orientación de las fibras, mientras que los papeles manuales coreanos mostraron bajos valores de intensidad. Esta diferencia parece deberse a las variaciones en la acción de formar las láminas. Varios tipos de papel de muestra preparados en el laboratorio, mediante el método común de formación de lámina sin movimiento y por el sistema deslizante, mostraron respectivamente valores bajos y altos de intensidad de orientación. Adicionalmente, la cara de la rejilla para la formación de lamina por deslizamiento dio un valor de intensidad de orientación mayor que la superficie superior. Este hecho fue lógicamente explicado en términos de deslizamiento de fibras y de nivel de deshidratación, y por consiguiente sugiere su aplicabilidad para distinguir ambos lados en los papeles de documentos antiguos. La aplicación de esta técnica a documentos de la familia Shimadzu, entre 1606 y 1859, indicó altos valores de orientación, sugiriéndose que el método de formación de lámina por deslizamiento ya estaba establecido en el siglo XVII en Japón. Los papeles de los libros sagrados del budismo coreano, manufacturados entre los siglos XI y XVI, mostraron bajos niveles de intensidad en la orientación, y las diferencias entre ambas caras del papel fueron mínimas. Esto indica que los papeles fueron elaborados por el método común de formación de lámina sin movimiento, método empleado con una oscilación lateral.*