

Permanence, Durability and Unique Properties of Hanji

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ABSTRACT

This research project presents new information about the permanence and durability of contemporary Korean handmade papers, explains the particular methods of traditional *hanji* papermakers while introducing the possibilities of utilizing the products of Korean papermills in conservation. Traditional Korean papermaking uses a unique technique, known as *webal*, to form a sheet which distributes fibers evenly in both directions theoretically resulting in less specific grain direction and an expansion/contraction rate which is even in both directions. In addition, Korean paper employs an exclusive use of paper mulberry known as *chamdak* or *dak* in contrast to the typically mixed fiber furnish of Chinese papers. Like most East Asian papers, the pH of Korean paper is alkaline or neutral. The typical alkalis used to prepare fibers are soda ash (Na_2CO_3) or caustic soda (NaOH). A variety of contemporary samples of Korean papers have been artificially aged and evaluated according to TAPPI standards under the direction of the Research and Testing Laboratory of the Library of Congress. This project will present interesting data concerning tensile strength, brightness, and pH before and after aging as well as expansion and contraction measurements. The results are very promising for the possibility of using Hanji for conservation treatment. One of the suggested advantages of using Hanji may be in the lack of strong grain direction providing a stable and non competing repair or lining paper.

I. HANJI: KOREAN HANDMADE PAPER

I.1 History

Many historians say that paper was invented by Ts'ai Lun in 105 C.E. in China and some say even earlier. There is no written record that explains when papermaking skills spread from China to Korea. It is believed that papermaking might have been practiced in Korea as early as the 3rd century C.E. based on a piece of paper found in an ancient tomb, *Chehyupchong* (108 B.C.E. - 313 C.E.).

Korean papermakers established their own methods of papermaking, probably sometime between the 3rd century C.E., and 751 C.E. when the earliest known extant Buddhist text was printed in Korea, the Dharani Sutra, the *Mugujungwangdedaranigyung*. The sutra was printed on paper made of paper mulberry called *dak* in Korean (kozo in Japan). During this time (the 3rd to 7th centuries C.E.) the Korean papermakers developed and adapted methods to suit materials that were locally available. In 610 C.E., Japan received instructions on papermaking from a Korean Buddhist monk, *Damjing*, together with ink sticks, a millstone and colorants. Through the centuries, *Hanji* became widely used not only for calligraphy and painting but also for flooring, window coverings, crafts and so on.

I.2 Unique Papermaking Methods

The Korean methods of papermaking established during this time include: a sheet formation technique called *webal* using a Korean style mould, a paper layering technique yielding papers called *yumyangji*, and the method of burnishing called *dochim*.

The *webal* method of sheet formation distributes fibers evenly in both directions resulting in paper with no strong grain direction. This study has established that *webal* papers have an expansion/contraction rate that is even in both directions, a property which could be very useful for paper conservation. *Yumyangji* papers are strong and even, resulting from alternating the layers when couching a sheet. *Dochim* papers have a tighter surface from the burnishing or calendering of the paper surface.

Very few papermakers continue to make papers today using these particular labor intensive, highly skilled methods. It is an honor to present these results to the conservation community to increase the range of mulberry papers available and to bring recognition to the unnamed craftspeople who continue their tradition of hand papermaking.

1.3 Materials



Fig. 1 *Dak*, paper mulberry inner and outer bark

Paper mulberry, *Dak* (Fig. 1)

The fibers used to make *Hanji* are from indigenous trees grown and harvested in Korea: *Broussonetia kazinoki* Sieb, *dak* tree or *chamdak* tree, *Broussonetia papyrifera* (L) Vent., *dak* tree or *kuzi* tree, *Edgeworthia papyrifera* Sieb, *samjidak* tree, *Wikstroemia trichotomia* ((Thunb) Mokino), *sandak* tree. *Dak*, paper mulberry, is the primary fiber used to make *Hanji*. *Samjidak* and *Sandak* are less common.

Through a small survey and analysis of fibers from Korean books from the 15th century to 20th century at the Library of Congress, it is possible to suppose that *Dak* was the major fiber used in Korean book publishing papers. None of the surveyed papers had mixtures of other fibers such as rice straw or bamboo. Each fiber sample was carefully

chosen from the book paper and examined with compound microscope. (100x) *Dak* fiber from these early books appeared identical to the *Dak* fibers in modern handmade papers.

Alkali, Cooking Agent

Traditionally, ashes obtained from burning the stems of plants, such as soybeans, chili, husks or buckwheat were used as cooking agents to remove the non-cellulosics from the fiber. Sometimes lime (calcium oxide, CaO) was used with wood ash (sodium or potassium hydroxide), but today, soda ash (sodium carbonate, Na₂CO₃), or caustic soda (sodium hydroxide, NaOH) is used.

Bleaching methods

Before beating, fibers are sun bleached for about 5-7 days for top quality papers. Sometimes a chemical, such as sodium hypochlorite (NaOCl) is used to shorten the process of removing specks and to whiten the fibers for lesser quality papers. These "whitened" papers can be re-colored to appear like non-chemically bleached papers.

Mould and Screen (Fig. 2)

The Korean mould does not have an upper frame or deckle to hold the fibers. The screen rests on a wooden mould with extended "handles" formed by the long sides of the mould. The screen is mainly composed of bamboo or grasses that are joined to create the long laid "lines". The splints are bound traditionally using twined silk threads coated with persimmon juice. The chain lines of the screen are parallel to the long side of the mould, a distinguishing mark of *Hanji*.



Fig. 2 Mould and screen for Webal method



Fig. 3 Cooking white bark with alkali to remove non-cellulosics

Fiber Preparation

Cooking *dak* takes place twice, first it is steamed to remove outer black bark and second to soften the inner white bark before beating. (Fig. 3, 4) During the second cook, the inner white bark is steamed or boiled in an alkali solution for about 3 hours to remove non-cellulosic impurities and to begin fiber separation. Fibers are rinsed well after boiling and bleached by the sun or with bleaching agents to lighten the color. (Fig. 5) For lesser quality papers, sometimes color is added back in to give the appearance of being unbleached. After this process, any dark spots left from the outer bark are removed by hand.



Fig. 4 Evaluating the white bark during cooking



Fig. 5 Rinsing the cooked white bark after cooking

Beating (Fig. 6)

Refined *dak* fiber is traditionally beaten by hand on a stone or wooden panel. Wooden stampers are still used. The knife style beater is also used to separate long fibers. It is known as *naginata* in Japanese. Hollander beaters are used for higher yield production.



Fig. 6 Traditional beating method with stick



Fig. 7 Dispersal agent: Dakpool, Hibiscus manihot

Fiber dispersal agent (Fig. 7)

Hibiscus manihot L., *Dakpool*, *Hwang chok kyu*. The liquid from the root consists of water, lime, sugar, starch, Arabinose, Rhamnose, Galactouronic Acid, Galactose, Lignin, and Protein. The agent helps to disperse fibers evenly, to stop long fibers from entangling, to separate the wet paper easily while stacked, and to help form an even thickness of paper by slowing the water drainage through the screen.

Webal Sheet Formation

Dak fibers are put into a vat filled with water, stirred with a stick, and mixed thoroughly. *Dakpool* is added to help the fibers disperse evenly and to stop them from sinking in the water during the sheet formation. The unique traditional Korean technique of sheet formation, *webal*, is one of the important characteristics that differentiate Korean paper from other Asian papers. The mould is suspended by only one central string at the far end of the mould. The papermaker scoops the fibers onto a mould which has no top frame or deckle by dipping the closest side of the mould into the vat. The papermaker pulls the mould towards the front of the vat and then quickly lifts the closest end of the mould to let the fibers flow off the opposite side. (Fig. 8, 9) The papermaker then dips the left side of the mould to pick up fibers and swings the mould from left to right, letting the fibers flow off the right side. (Fig. 10, 11) This is repeated, dipping the right side first to even the distribution of fibers. (Fig. 12) This process allows for the formation of a paper without one strong grain direction.



Fig. 8 Initial dip of Webal method of sheet forming



Fig. 9 Fibers flowing off the opposite side of the mould



Fig. 10 Dipping left side of the mould into vat



Fig. 11 Swinging mould to remove excess fibers



Fig. 12 Dipping the right side of the mould into vat



Fig. 13 Mould and deckle for Ssangbal method

Ssangbal Sheet Formation

After the 1900's, Korean papermakers started using the Japanese way of sheet formation called *ssangbal*, as well as *webal*. For the *ssangbal* method, a mould with a deckle is used. (Fig. 13) The papermakers dip the mould in the water towards themselves first, shake the mould front to back repeatedly and then slant the mould down at the far edge to toss off excess fibers. (Fig. 14, 15, 16) Fibers align themselves with the direction of motion which makes a clear grain direction in the paper. *Ssangbal* papers are dipped multiple times, but wet sheets are not usually layered.



Fig. 14 Scooping fibers onto mould with deckle



Fig. 15 Shaking mould front to back while water drains



Fig. 16 Excess fibers are tossed off top of mould

Webal Layered Papers

During couching, one sheet is layered on top of another sheet from the opposite direction to even out the thickness of the paper. (Fig. 17, 18, 19) All *webal* paper is multi-layered and is called *Yumyangji* (Yin-Yang sheet). A string is used to separate the layered sheets to ease parting. This process ensures a strong paper.



Fig. 17 Sheet is couching onto post of wet sheets



Fig. 18 Rolling log across post of wet sheets to remove bubbles



Fig. 19 String used to separate sheets on post of wet sheets

Drying

Traditionally papers are air dried on wooden boards. (Fig. 20) These days a steam heated stainless steel panel is used for drying by brushing the paper onto the panel to dry. (Fig. 21)

Dochim, Burnishing

Korean handmade papers can be burnished by a process called *Dochim*. One damp sheet is laid between every ten sheets, and one hundred sheets are then piled up in this way. A wooden board is placed on the top of this stack and weighed down with stones. The stack is left for a day to let the moisture distribute through all the papers. The board is removed and the stack is beaten with a wooden stick, or a wooden hammer powered by a watermill. If requested, very dilute rice starch paste is applied on the surface of each sheet of paper. It acts like a sizing agent and provides abrasion resistance. Through this process, the paper texture becomes smoother and the fibers become more compact.



Fig. 20 Drying by brushing individual sheet onto heated stainless steel drum



Fig. 21 Traditional method of drying sheets on wooden boards

2. SCIENTIFIC ANALYSIS OF HANJI

2.1 Introduction

This project evaluated a variety of *dak* (mulberry) papers made in Korea to determine their suitability for use in conservation. Four handmade papers identified as high quality papers, two bleached and colored papers, a paper with 70% pulp and a machine made paper were chosen. Of the four high quality papers, three were made using the *webal* method and one with the *ssangbal* method of sheet formation.

The papers were evaluated according to TAPPI standards under the direction of the Research and Testing Laboratory of the Library of Congress. The intention was to evaluate their physical strength, brightness and pH and to predict their "permanence" or lasting quality by comparing the decline they suffered in physical strength, brightness and pH after subjecting the papers to accelerated aging at 90°C and 50% relative humidity for 28 days. Tensile energy absorption was chosen to evaluate strength rather than fold endurance due to the extreme thinness of some of the samples along with the frequency of larger fiber clumps. Expansion and contraction measurements were taken by measuring before and after wetting out.

2.2 Choice of Papers

Eight paper samples were chosen, produced in South Korea according to the differences of sheet formation, alkali, bleaching and drying method. No papers contain a filler or starch sizing. (See Table 1)

Sample No.	Materials	Sheet formation	g/m ²	Thickness (mm)	Alkali	Bleaching method	Drying method
W1	Dak 100%	Webal	19.1	0.09	soda ash	sun bleach	wood
W2	Dak 100%	Webal	24.6	0.09	soda ash	sun bleach	wood
W3	Dak 100%	Webal	38.6	0.13	soda ash	sun bleach	steel
S1	Dak 100%	Ssangbal	12.8	0.09	soda ash	sun bleach	wood
S2	Dak 30%, pulp 70%	Ssangbal	45.7	0.13	caustic soda	sun bleach	steel
S3	Dak 100%	Ssangbal	20.9	0.11	caustic soda	sodium hypochlorite + recolored	steel
S4	Dak 100%	Ssangbal	52.0	0.18	caustic soda	sodium hypochlorite + recolored	steel
MM1	Imported dak 100%	Machine made	17.5	0.10			

Table 1. Selected Paper Samples

2.3 Testing and Evaluation Methods

Artificial Aging: TAPPI 402 and LC Humid Oven Aging Procedure

Sample pieces of each paper were preconditioned according to TAPPI 402 for 48 hours in a 23°C and 50%RH TAPPI room. The samples were interleaved with waterleaf chemically purified wood pulp paper and hung on racks. The samples were aged, freehanging, for 28 days in a Thermotron humid aging oven at 90°C and 50% RH.

pH: TAPPI 509

pH values were measured by the cold extraction method modified by slurring the sample pulp before measuring with the 809 Titrand by Metrohm. One reading was taken before and after aging of each sample paper.

Brightness: TAPPI T452

The brightness readings were measured by directional reflectance at 457nm using the Brightmeter Micro S-5 by Technidyne Co. Three readings were taken of each sample paper before and after aging. Due to the thinness of papers, all readings were taken through eight layers to achieve an even Brightness reading. The readings were averaged.

Tensile Energy Absorption: TAPPI T494 and TAPPI T 402

After conditioning samples according to TAPPI T 402, standard sized strips were cut on a Thwing precision cutter 1.0 cm wide. The samples were cut in the Machine Direction only (a.k.a. with the grain, along the chain lines). Tensile strength was measured using an Instron 4301 in conjunction with Instron Series IX software. The method specifics followed LC Method #1: sample length between jaws was 100 mm and crosshead speed was 20.00 mm/min. Ten readings were taken of each sample paper except for MMI for which 5 readings were taken due to lack of sample. The Tensile Energy Absorption measurements are reported here in N/mm.

Expansion/Contraction Rates of *webal*, *ssangbal* and Japanese handmade papers were compared. Squares of paper were cut to be 10cm x 10cm. They were measured in both directions after wetting out completely and drying between felts with no weight.

SEM

Webal papers and spots in the machine made paper were photographed with the Cambridge S200 scanning electron microscope.

X-Ray Microanalysis

Traces of metals in the machine made paper were characterized using X-Ray microanalysis with the Kevex (sigma 2) fluorescence probe.

3. RESULTS

pH

Unbuffered mulberry papers typically have a pH in the neutral range. The pH of all tested papers remained within a neutral or close to neutral range before and after aging. MMI had Calcium deposits. None of the other papers are said to have alkaline reserve. (See Table 2 & Chart 1)

Korean Paper	Before Aging	After Aging	Change
W1	7.14	6.79	-0.35
W2	7.32	6.68	-0.64
W3	7.74	6.65	-1.09
S1	8.19	7.88	-0.31
S2	7.18	6.63	-0.55
S3	6.84	6.84	0
S4	7.18	6.63	-0.55
MM1	7.19	7.38	+0.19

Table 2. pH changes before and after aging

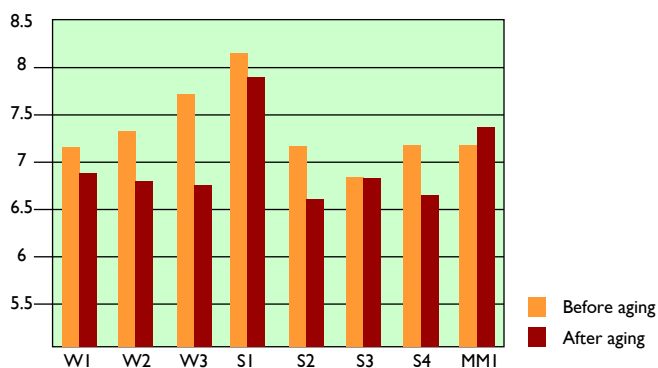


Chart 1. pH before and after aging

Brightness Test

A color change of 5 points is visible. Groundwood paper can change approximately 20 pts. if aged for 28 days. Significant color change is an indicator of degradation. (See Table 3 & Chart 2)

Korean paper	Before aging (pts)	After aging (pts)	Change (pts)
W1	47.7	45.1	-2.6
W2	47.7	47	-0.7
W3	57.3	52.5	-4.8
S1	53.1	53.8	-0.7
S2	75.5	63.9	-11.6
S3	74.0	63.6	-10.4
S4	56.5	53.0	-2.5
MM1	80.9	56.3	-24.6

Table 3. Brightness changes before and after aging

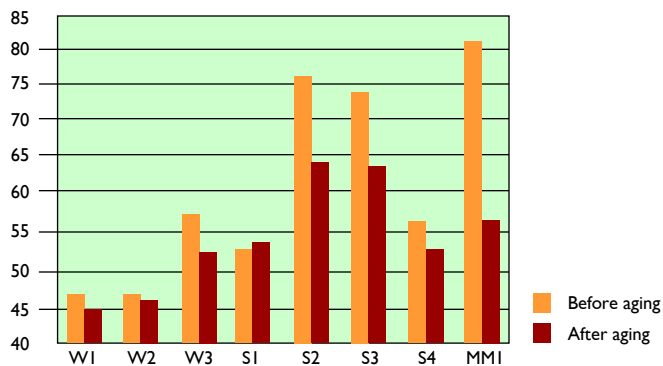


Chart 2. Brightness before and after aging

Tensile Energy Absorption

High quality paper should retain at least 80% of its T.E.A. after aging for 28 days in a free hanging oven method. This testing method has a high standard deviation rate particularly in this case when there can be a number of larger fiber clumps. Differences within a 10% range are not considered significant. (See Table 4 & Chart 3)

Korean paper	g/m ²	Before Aging		After Aging		Retention (%)
		Mean (N/mm)	Standard Deviation	Mean (N/mm)	Standard Deviation	
W1	19.1	0.03906	0.00364	0.03801	0.00636	97.3
W2	24.6	0.03592	0.00642	0.02956	0.00482	82.3
W3	38.6	0.08966	0.01082	0.10592	0.02553	100
S1	12.8	0.02539	0.00328	0.02115	0.00671	83.3
S2	45.7	0.01447	0.00261	0.01728	0.00325	100
S3	20.9	0.02152	0.00232	0.01781	0.00201	82.8
S4	52.0	0.04817	0.01649	0.02707	0.00530	56.2
MM1	17.5	0.01037	0.00222	0.00365	0.00121	35.2

Table 4. Tensile Energy Absorption (Mean & S.D.) before and after aging

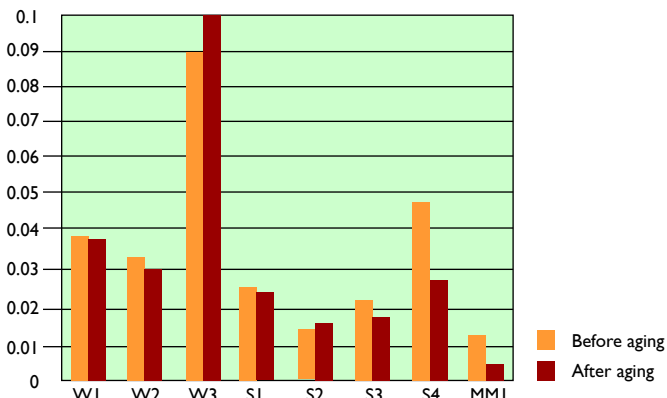


Chart 3. Tensile Energy Absorption (Mean) before and after aging

Webal and Ssangbal Expansion and Contraction Rates (See Table 5)

- Webal papers expanded and contracted evenly in both directions and did not change final dimensions.
- One ssangbal paper expanded and contracted evenly and did not change final dimensions. The other ssangbal paper expanded and contracted evenly and became 0.05 cm smaller in the cross grain direction.
- The two Japanese handmade kozo papers made in the nagashizuki (a.k.a. ssangbal) method expanded differently in both directions and became 0.1 to 0.05 cm smaller in both directions.

These results demonstrate that the webal papers do not have a dominant grain direction. The ssangbal and nagashizuki papers do have a grain direction that is specific to each paper.

Korean & Japanese Paper	Dry With grain X cross grain (cm)	Wet (cm)	Upon drying (cm)	Change (cm)
W1	10 x 10	10.1 x 10.1	10 x 10	None
W2	10 x 10	10.1 x 10.05	10 x 10	None
S1	10 x 10	10.1 x 10.05	10 x 10	None
S2	10 x 10	10.1 x 10	10 x 9.95	- 0.05 cross grain
usui usu mino	10 x 10	10.1 x 10	9.9 x 9.9	- 0.1 both directions
hon mino	10 x 10	10.1 x 10.05	9.9 x 9.95	- 0.1 grain - 0.05 cross grain

Table 5. Expansion/Contraction Rates

SEM (Fig. 22)

This photograph taken at 152X shows the layers of fibers that are oriented in varying directions: the result of the *webal* method of papermaking. This contributes to paper strength and even expansion/contraction rates.

X-Ray Microanalysis (Fig. 23)

Small brown spots were apparent over the sheet of the machine made paper (MM1) after aging for 28 days. X-ray analysis characterized many spots as containing iron. Calcium and chlorine were also characterized in the paper. This photograph was taken at 1260X and shows a tiny spot (20 micrometers) in the shape of a hook that was characterized as iron.



Fig. 22 SEM photograph of Dak fiber distribution in Webal formed paper (152X)



Fig. 23 SEM photograph of iron spot (20 micrometers) in MM1 paper sample (1260x)

4. CONCLUSION

This study of Korean *dak* papers looked at a variety of Korean handmade papers to evaluate for permanence and durability. The tests results indicate that the four papers (W1, W2, W3, S1) identified as "high quality" are excellent papers with high ratings for permanence and durability. These handmade 100% *dak* papers were cooked with soda ash and sun bleached. In a previous study, it was verified that using a milder alkali aids the stability of Japanese paper. (Uyeda et al., 1999, 119-125) The higher quality Korean papers retained over 80% of their strength and did not visibly discolor after aging. These papers are made using both *webal* and *ssangbal* methods.

The results for the "lesser quality" handmade papers are not as clear. Of the two 100% *dak* papers that were cooked with caustic soda, chemically bleached and recolored, one paper (S3) showed some discoloration and yet retained 80% of its strength. The other paper (S4) did not discolor, but lost almost 50% of its strength. The 70% pulp paper (S2) that was cooked with caustic soda and sun bleached, retained 100% of its strength. This paper discolored visibly however not significantly.

The machine made *dak* paper discolored significantly, lost 65% of its strength and developed brown spots after aging. In roughly half of the spots, iron was characterized, but in the other half, iron was difficult to detect.

One can draw the conclusion that the "higher quality" papers are excellent candidates for conservation use, keeping in mind that the test results refer to these particular paper samples and each batch of paper has the potential to be different. The "lesser quality" papers pose too many uncertainties to consider for conservation. The machine made paper chosen for this test is not suitable because it discolored and lost significant strength. It may be that other Korean machine made papers are suitable, and would need to be evaluated before using for conservation purposes.

The *webal* papers chosen for this study had even fiber distribution and were measured to maintain a constant expansion/contraction rate in both directions. This presents the possibility of a paper with useful qualities for some conservation methods such as linings.

The characteristics which cannot be measured by TAPPI methods are the luster of the fibers and the beauty of the sheet that sings out as one handles the "higher quality" papers from Korean papermakers. These papers speak of a long tradition and the finesse of the papermakers who make them. This study was undertaken with much appreciation and hope for papermakers to continue to make such papers.

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