Measuring the dimensional stability of paper

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Abstract
This article discusses the development of a test method to measure the dimensional stability of paper. Two papers (one sized, one not sized) were used in this investigation. Simulated washing in distilled water was undertaken followed by drying under environmental conditions of 20 $\pm$ 2ºC and 65 $\pm$ 4% RH. The effect of up to five washing and drying cycles on the dimensional stability of the papers was investigated.

Introduction

Conservators wash paper in water and other solutions to remove soluble materials (e.g. dirt, decomposition products) and/or to reduce acidity (e.g. Clapp 1987, Keyes 1978, Nelson et al. 1982, Sugarman and Vitale 1992, Tang and Jones 1979, van der Reyden 1992). Paper reportedly expands when wet and then shrinks as it dries (e.g. Clapp 1987, Keyes 1978, Wessel 1970). The fact that cellulose fibres expand preferentially in the transverse compared to the longitudinal direction is well recognised (e.g. Collins 1939), as is the tendency of paper to expand in the cross direction more than the grain direction with increasing atmospheric humidity and to contract more in the cross direction than the grain direction with decreasing atmospheric humidity (Turner 1991). Dimensional changes are also thought to be affected by the length, orientation, and degree of hydration of the fibres, and by the thickness/density of the sheet, and they are a matter of "severe concern in paper conservation" (Keyes 1978: p4).

A procedure for determining percentage change in length of paper specimens cut in both directions after wetting (but not subsequent drying) is specified in ISO 5635 (International Organization for Standardization 1989). Specimens are immersed in distilled water until the maximum change between two small slits cut in the paper has occurred, which the Standard states "usually takes about 15 minutes" (International Organization for Standardization 1989). ISO 5635 can be compared to the Standard methods for the measurement of dimensional stability of fabrics, which allow for the percentage dimensional change that may have occurred in both the width and length of a fabric specimen to be evaluated over a number of wetting and drying cycles (International Organization for Standardization 1984, International Organization for Standardization 1994b). The aim of this work was to determine the effects of five wetting and drying cycles on the dimensional stability of two papers.

Method

Two papers (unaged) were used in this work: i) Saunders Waterford watercolour paper, a mouldmade, 100% cotton, acid-free paper that is sized using alkyl ketene dimmer and weighs 300 g/m^2 and ii) Arches 88 printmaking paper, a mouldmade, 100% cotton, acid-free paper that is not sized and weighs 300 g/m^2 (Fine Arts Papers, Christchurch, New Zealand). Five single sheets (x = 760 mm, y = 560 mm) of each paper were used.

Sheets were stored under environmental conditions of 20 $\pm$ 2°C and 65 $\pm$ 4% RH for 24 hours before specimens were cut, and tested under these conditions (International Organization for Standardization 2005). It is acknowledged that these environmental conditions are different to those used in the paper industry (International Organization for Standardization 1990), however the aim of this work was to measure the dimensional stability of two papers, and not to compare these properties to those in the published literature.[1]

After conditioning, the outer 15 mm of each sheet was discarded and one dimensional-stability specimen (300 × 300 mm) cut from each sheet

1 Mean reported relative humidity data for New Zealand (1971–2000): 79.8% RH, minimum 65.0% RH, maximum 94.3% RH (http://www.niwa.cri.nz/).

of paper (International Organization for Standardization 1994a). Three pairs of reference points 200 mm apart were marked in the length (x) and width (y) directions on the dimensional stability specimens with a HB pencil (International Organization for Standardization 1994b) (Figure 1). Specimens were placed on a Mylar™ sheet (transparent polyester; ~400×400 mm) and immersed in distilled water (20 ± 2°C) for 30 minutes. The Mylar™/paper composite was removed, held vertically for 20 seconds, and dried horizontally on acid-free blotting paper on glass, a method commonly used in the conservation laboratory at Christchurch Art Gallery when drying paper artefacts.

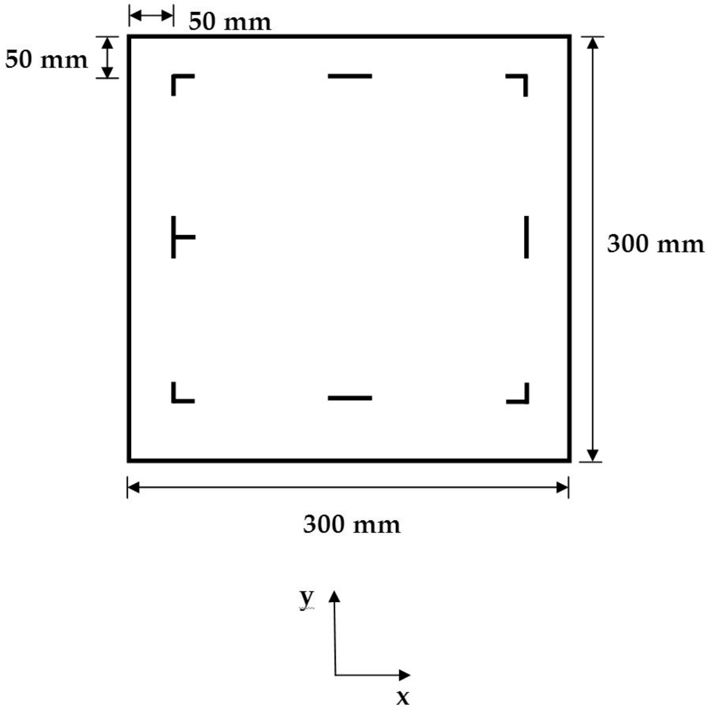


Figure 1. Dimensional change specimen
(dimensions and position of marked reference points).

The length (x; n[2] = 3; mm) and width (y; n = 3; mm) of each dimensional-stability specimen were measured before testing commenced (i.e. original dimensions), immediately after removal from the distilled water, and after a 24-hour drying period.[3] Specimens were subjected to five wetting and drying cycles, representing a (typical) five-cycle conservation treatment in aqueous solutions of washing, deacidifying, bleaching, washing, and deacidifying. Fresh distilled water was used for each cycle. The percentage changes in length (Δx; %) and width (Δy; %) were calculated for each data set:

i) after wetting with reference to the previous dry dimensions
ii) after drying with reference to the previous wet dimensions
iii) after drying with reference to the previous dry dimensions.

Mean and standard deviation data were calculated using Microsoft Excel X for Mac. Univariate analysis of variance (ANOVA) and repeated measures ANOVA were used to identify significant changes in properties after and during five wetting and drying cycles using SPSS 11.0.3 for Mac OS X. When Mauchly's test of sphericity was significant, the Greenhouse-Geisser correction was used (SPSS Inc. 2003).

Results and discussion

On comparing the dry dimensions after five wetting and drying cycles to the original dimensions, the two papers had behaved differently (F[4] $_{1,16}$ = 634.344, p[5]$\leq$0.001). The sized paper was significantly larger (mean x = 0.20%; mean y = 0.52%), and the not-sized paper was significantly smaller when compared to the original dimensions (mean x = -0.82%; mean y = -0.88%). As expected, significantly different behaviour was observed in

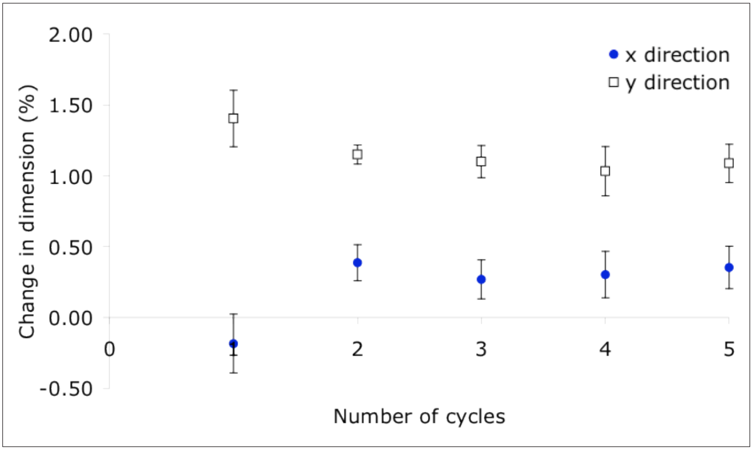
2 n is the number of replicates tested.

3 Paper artefacts are typically left to dry overnight in the conservation laboratory at Christchurch Art Gallery (L. Campbell 2005: personal communication).

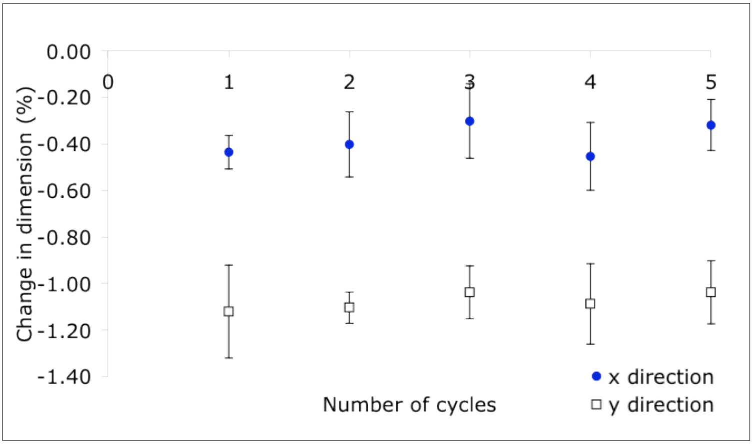
4 F = F-statistic; a large F-statistic indicates that the differences between the sample means are too large to have occurred by random error alone, implying evidence of a sample effect. The first subscript refers to the degrees of freedom for the variable and the second to the degrees of freedom for the error.

5 p = significance level.

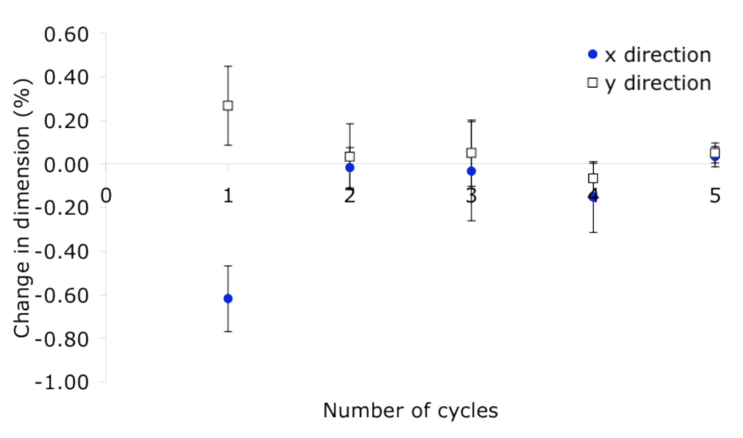
Figure 2. Changes in dimensions for Saunders (sized) (means, standard deviations).
2a. Comparison of wet dimensions to dry dimensions of previous cycle.



2b. Comparison of dry dimensions to wet dimensions of previous cycle.



2c. Comparison of dry dimensions to dry dimensions of previous cycle.

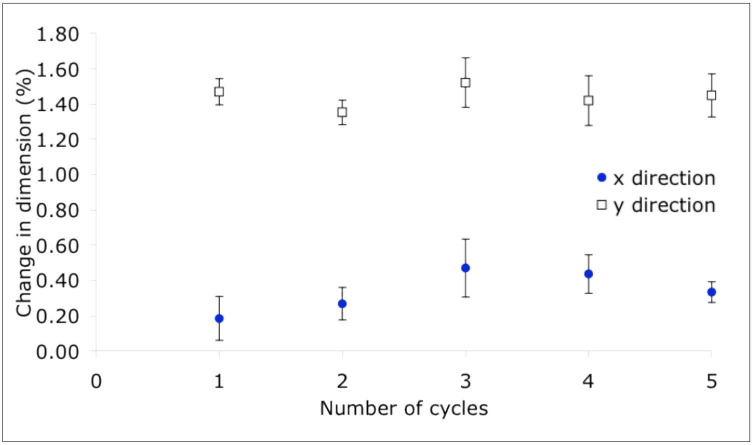


the x and y directions ($F_{1,16} = 8.912$, $p \leq 0.01$). Wetting changed dimensions compared to previous dry dimensions significantly (although weakly) among cycles ($F_{4,64} = 2.668$, $p \leq 0.05$), however this was affected by the paper direction and the type of paper tested ($F_{4,64} = 18.844$, $p \leq 0.001$; $F_{4,64} = 3.451$, $p \leq 0.05$) (Figures 2a and 3a). The effect of drying from the wet state did not vary among cycles ($F_{2.198,35.170} = 0.724$, p = NS) (Figures 2b and 3b). Dry dimensions compared to the previous dry dimensions varied among cycles ($F_{4,64} = 3.756$, $p \leq 0.01$); direction but not paper type affected this variation ($F_{4,64} = 12.366$, $p \leq 0.001$; $F_{4,64} = 2.067$, p = NS) (Figures 2c and 3c).

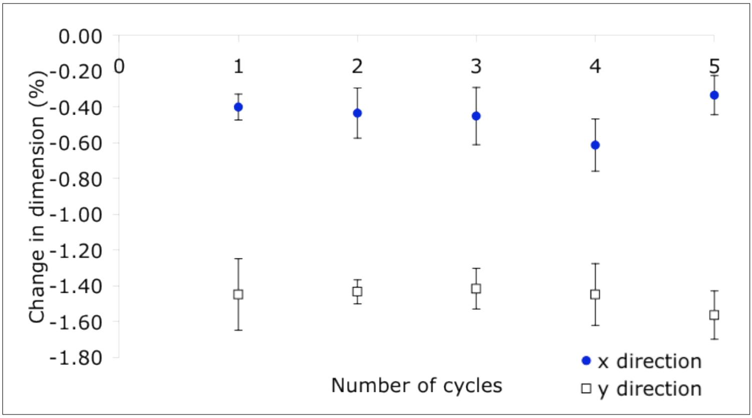
Sized paper

After wetting for the first time, the paper shrank in the x-direction (mean = -0.18%), but was larger in the y-direction (mean = 1.40%) compared to the original dry dimensions (Figure 2a). On drying from this initial wetted state, both dimensions were smaller than they had been when the paper was wet (mean x = -0.44%; y = -1.12%) i.e. the paper shrank in both directions (Figure 2b). However, a comparison of the dry dimensions after the first cycle compared to the original dry dimensions, indicated that the paper had shrunk in the x-direction (mean = -0.62%), but was larger in the

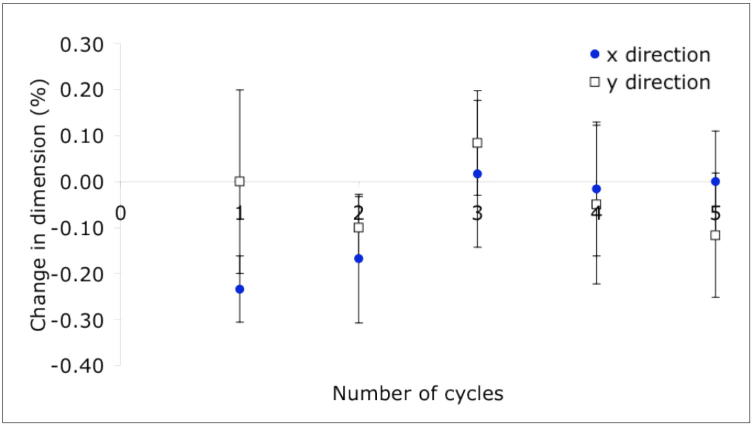
Figure 3.
3a. Changes in dimensions for Arches paper (not-sized) (means, standard deviations).



3b. Comparison of dry dimensions to wet dimensions of previous cycle.



3c. Comparison of dry dimensions to dry dimensions of previous cycle.



y-direction (mean = 0.27%) (Figure 2c). For cycles 2–5, the dimensions of the paper were larger in both directions when wet compared to the dry dimensions of the previous cycle (Figure 2a). After drying, the dimensions were smaller compared to the previous wet dimension (Figure 2b). The dry dimensions were similar to those measured after the previous cycle (Figure 2c). After five wetting and drying cycles, the paper was larger in both x and y directions compared to the original dimensions (mean x = 0.20%; mean y = 0.52%).

Not-sized paper

After wetting for the first time, the paper expanded in both directions (mean x = 0.18%; mean y = 1.47%) compared to the original dry dimensions (Figure 3a). On drying from this initial wetted state, the paper shrank in both directions (mean x = -0.40%; y = -1.45%) (Figure 3b). On drying after this first wetting cycle, the paper was smaller in the x-direction compared to the original dry dimension, however, the y-direction dimension was the same as the original dry dimension (Figure 3c). For cycles 2–5, the paper expanded in both directions when wet (compared to the dry dimensions of the previous cycle), and then shrank in both directions on drying (Figures 3a and 3b). The dry dimensions were similar to the dry dimensions of the previous cycle (Figure 3c). After five wetting and drying cycles, the paper was smaller compared to the original dimensions (mean x = 0.82%; mean y = 0.88%).

Conclusions

The magnitude of the dimensional changes measured in this work are important when assessing papers (such as those examined) for lining deteriorated and fragile works of art that might have a friable material present, e.g. gouache. Measuring the dimensional stability of potential papers for lining could be used as a tool to assess any likely impact of using the lining paper on a damaged original artwork. Coefficient of variance (CV) data were relatively low (< 5%) and the results obtained (regarding expansion and shrinking patterns) were generally as expected, giving confidence in the test method used. Several interesting points were observed:

i) On wetting the sized paper for the first time, the x-direction dimension was smaller (-0.18%) and the y-direction larger (1.40%) compared to the dry dimension. For the not-sized paper, both dimensions were larger when wet compared to the original dry dimensions.
ii) After five wetting and drying cycles, the sized paper was significantly larger (mean x = 0.20%; mean y = 0.52%) and the not-sized paper was significantly smaller (mean x = -0.82%; mean y = -0.88%) compared to the as-received condition.

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