# Measuring cockling on-line in high speed inkjet printing

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## Abstract

*Cockling of paper is unwanted out-of-plane deformation arising from variations in humidity. Paper is typically characterised by measurements of dimensional changes when slowly changing the humidity or by measurements of cockling on printed paper after printing. Here, a novel experimental set-up is presented in which cockling can be measured on-line at high speed in the inkjet printing process. Cockling was recorded as a function of time. It is shown that the cockling is several orders of magnitude higher during printing than after printing. Measurements on three papers are reported.*

## Introduction

Cockling of paper manifests itself as high frequency out-of-plane deformation with small amplitude arising from changes in humidity. At a microscopic level, the fibers in the paper swell mainly in the cross direction during water uptake. Cockling of paper is affected by parameters such as fiber orientation, drying time, paper web tension and local variations in paper properties [1-8]. In the case of printing, the printing technology and the printing conditions are very crucial in addition to the above mentioned parameters. In addition to a visually unsatisfying print result originating from the out-of plane deformation, cockling may cause paper transportation and rewinding problems. The time-dependency of the cockling may furthermore be of practical importance when printing several colors, since the quality of the print decreases if the various colors are misplaced relative to each other as a consequence of dimensional instability of the paper. Researchers have focused on verifying models by offline cockling measurements and by measurements of paper deformation originating from changes in moisture [1,2,5,8]. These measurements are relevant, but do not capture the dynamic processes occuring in the paper during printing. Therefore, a novel experimental set-up was developed in which cockling can be measured on-line in an inkjet printing device. Measurements on copy paper, high-speed inkjet paper and pilot paper were carried out.

## Experimentals

The setup consists of a belt rig, a Kodak Versamark DS5240 inkjet printing system, height measurement devices and control systems (Figure 1). The paper to be studied is rolled around the two cylinders of the belt rig. The rotational speed of the cylinders is controlled by an engine and a stepping encoder. The paper runs over a plate of stainless steel at which the printing equipment and the height measurement device is placed. The height measurement device is based on the laser triangulation method and measures the height at a fixed position. During operation, the paper was moving and the height measured over a length of 100 mm. A square of 25 mm was printed once (100%K, water-based ink), and the cockling was recorded as a function of time every time the printed area passed the height measurement device (denoted Laser 1 in Figure 1).

Measurements were made at paper web speeds of 1 m $s^{-1}$ and 3 m $s^{-1}$. The paper web tension was controlled by adjustment of the distance between the two cylinders and by qualitative measurements utilizing a second height measurement device (denoted Laser 2 in Figure 1). Two settings of the web tension were defined. These settings are denoted 'loose' and 'stiff' below. On-line cockling measurements were made in the machine-direction (MD) and in the cross-direction (CD) of the papers, referring to the paper production process. In the case of CD-measurements, an A4 sized part of the paper web was replaced by an A4 sized sheet of the paper to be studied. The paper to be studied had been rotated 90° prior to fixation into the paper web. Five to ten measurements were made for each set of parameters, and the average values were calculated.

The amount of cockling as a function of time was evaluated by calculation of the extension of the curve recorded by the height measurement device at various times after printing, as compared to the curve recorded before printing. The term edge extension is used below to describe this parameter.

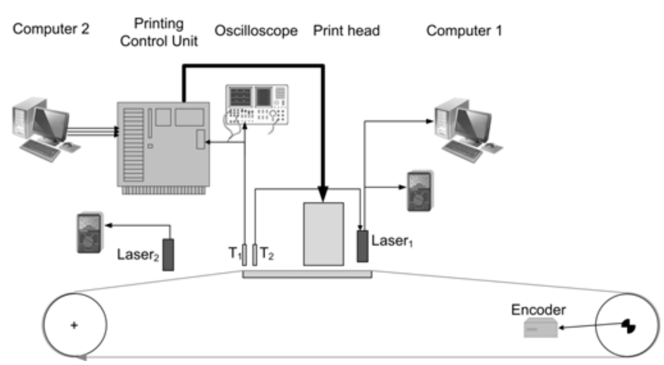


***Figure 1**. On-line cockling experimental setup*

Measurements were performed on copy paper, high speed ink jet (HSIJ) paper and a pilot paper. The latter was produced in a small paper machine at MoRe Research in a manner similar to commercial paper production, however in small scale and at a very low production speed. The pilot paper had not been surface sized. All three papers were uncoated.

The tensile stiffness index (TSI) of the papers was determined by measurements of the elastic modulus in MD and CD. Hygroexpansion of the papers was measured according to ISO 8226-1 and ISO 8226-2. Offline cockling measurements were made by utilizing a height measurement device based on the laser triangulation method. The height measurement device scanned the print sample in two dimensions. Prior to offline cockling measurements, a square (100%K) had been printed on the paper in an inkjet printer, followed by five minutes of drying at room temperature. The amount of cockling of each sample was estimated as the difference between maximum and minimum height of the measured area.

## Results & Discussion

Relevant paper properties of the copy paper, the high speed inkjet paper, and the pilot paper are presented in Table 1. The TSI value was calculated as the ratio of the E-modulus in MD and CD. The TSI value indicates that the fibers are more aligned in the copy paper than in the HSIJ paper. The low fiber distribution anisotropy indicated by the low TSI value of the pilot paper can be explained by the low paper production speed of the pilot paper.

The copy paper has the lowest basis weight of the three papers and may therefore be expected to exhibit a higher degree of cockling. A paper with a lower basis weight and therefore a lower bending stiffness tends to exhibit a higher cockling [5].

**Table 1: Paper properties**

| Paper | TSI | Grammage ($g\ m^{-2}$) | Thickness ($\mu m$) |
|---|---|---|---|
| Copy | 2.82 | 80.3 | 107 |
| HSIJ | 2.57 | 90.5 | 118 |
| Pilot | 2.27 | 91.9 | 131 |

The repeatability of the on-line cockling experimental set-up was evaluated before the measurements were performed. It was found that although small variations occurred between identical measurement conditions, the impact that different paper grades had on the measurement data were of much greater importance.

Figure 2 shows typical on-line cockling data where the height was measured with the paper web moving underneath the height measurement device, yielding the height of the sample along the paper web direction. As inkjet printing occurs, the paper cockles as revealed by the upper curve in Figure 2. Two peaks or more could often be detected upon measuring cockling on-line in CD. In the case of measurements in MD (data not shown), most often only one peak, having a smaller amplitude than the peaks shown in Figure 2, could be detected. This is in accordance with the fibers swelling mainly perpendicular to the fiber axis upon water uptake.

From data similar to the ones shown in Figure 2, the edge extension of the print sample could be calculated at various times. Measurements of the evolution of the edge extension at two paper web speeds are presented in Figure 3, showing that the paper web speed influences the cockling of the paper in important ways. At the higher paper web speed, the cockling is smaller and reaches its maximum value in a shorter time, corresponding to roughly 20 s. The higher speed of the paper web should result in faster evaporation of the ink and thereby faster drying. As the fibers in the paper swell after printing, an inner tension in the fiber network builds up. At a high enough inner tension paper deformation occurs. Considering that cockling reaches its maximum value after 20 s according to the data presented in Figure 3, it seems likely that efficient drying conditions can prevent the building up of the inner tension, thereby lowering cockling. It can however not be ruled out completely that part of the differences between the data in Figure 3 originate from differences in web tension as a consequence of different paper web speeds.

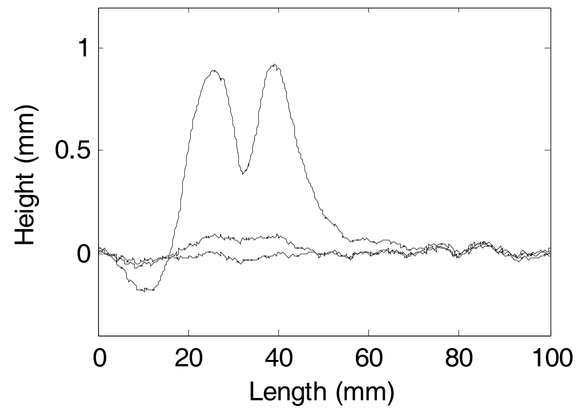


*Figure 2: Height along a print sample (Copy paper, CD, 1 m $s^{-1}$) in a moving paper web. Lower curve: before printing; middle curve: directly after printing; upper curve: approximately 5 sec after printing.*

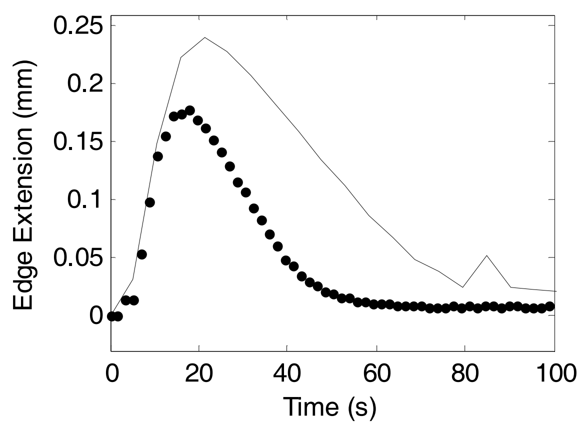


*Figure 3: Average edge extension of print on paper (HSIJ, CD, web tension: loose) as a function of time at a paper web speed of 1 m $s^{-1}$ (curve) and 3 m $s^{-1}$ (dotted curve).*

Average edge extension data on print samples run at a paper web speed of 1 m $s^{-1}$ are illustrated in Figure 4. For all papers investigated, maximum cockling occurred after 20 s to 30 s. Thereafter the cockling decreased, and a comparatively low value was reached after 80 s to 100 s. The six upper curves reveal that the cockling occurs mainly in the CD of the paper, as discussed previously. Figure 4 furthermore reveals that a stiffer web tension (open symbols) decreases the cockling of the papers. This is expected, since there is less freedom for lowering the inner tension by paper deformation at higher web tensions.

Among the three papers, the thinner copy paper exhibited the largest cockling peak in both CD and MD. The pilot paper showed the smallest cockling peak among the papers in CD, but not in MD. This may be due to the more isotropic fiber orientation in the pilot paper. The TSI values in Table 1 indicate that the fiber distribution was least anisotropic in the pilot paper, which can be expected to result in a smaller relative cockling difference between CD and MD for this paper.

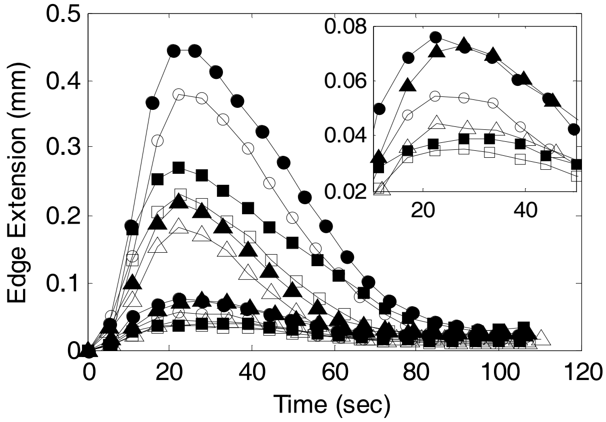


*Figure 4: Average edge extension of print on paper as a function of time at a paper web speed of 1 m s$^{-1}$. Filled and open symbols represent loose and stiff web tension, respectively. Circles: Copy paper; Squares: HSIJ paper; Triangles: Pilot paper. The top six curves represent cockling in CD and the six bottom curves represent cockling in MD. The small graph in the upper right corner is a magnification of the MD curves.*

For reasons of comparison, the hygroexpansion of the papers and the offline cockling of printed samples were measured. The data are presented in Table 2. Although the hygroexpansion measurements are characterised by slow variations in the moisture content, as opposed to the rapid change in water content in the paper during inkjet printing, the data shows that water has the largest impact on the elongation in the case of Copy paper.

**Table 2: Hygroexpansion (33%-84% RH) and offline cockling data.**

| Paper | Hygro-exp. MD (%) | Hygro-exp. CD (%) | Cockling (mm) |
|---|---|---|---|
| Copy | 0.19 | 1.08 | 0.549 |
| HSIJ | 0.12 | 1.03 | 0.325 |
| Pilot | 0.18 | 0.82 | 0.509 |

Also in the case of offline cockling measurements, the Copy paper exhibited the highest measurement value, corresponding to the lowest dimensional stability. As compared to the on-line cockling measurements, and referring to the peaks in Figure 4, the offline cockling value of the pilot paper is unexpectedly high, and the opposite holds for the HSIJ paper. The high off-line cockling for the pilot paper could be due to a more open structure of this paper with less fiber bonding revealed by the significantly higher thickness of this paper. Interestingly, the off-line cockling data is in better accordance with the on-line cockling measurement data after 100 s, although the uncertainty in the on-line cockling data is fairly large at this time interval. At this point the main part of the water has probably evaporated. It should furthermore be noted that, compared to the on-line cockling measurements, a different inkjet printer and ink was used for printing the samples prior to the offline cockling measurements.

A direct comparison between the on-line measurements and the off-line measurements should be done with caution. The measurements should rather be considered as complementary, and be used to get improved understanding of the complex processes of ink-paper interaction that result in cockling of paper.

## Conclusions

An experimental setup was developed in which cockling of paper during inkjet printing can be measured as a function of time. Measurements were made in the paper CD and MD at two paper web speeds, and at two paper web tensions. The results are in accordance with expectations, and can be explained by variations in fiber alignment, drying conditions, and release of inner tension by paper deformation. In the CD, the cockling frequency could be recorded. During printing, the cockling is several orders of magnitude higher than after printing. Moreover, the presented data shows that maximum cockling occurs 20 s to 30 s after inkjet printing at a paper web speed of 1 m s$^{-1}$. The experimental setup gives novel possibilities to investigate the dynamics of ink jet printing on paper.

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## Author Biography

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