CURL BASICS (revised)

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SUMMARY

Curl occurs when sheet layers expand unevenly:

1. *Differences can caused by the effects of fiber orientation, composition, bending, and passing a sheet through a xerographic fuser.*

2. *Most frequently differential fiber orientation develops from velocity differentials between the forming fabric and the slurry forming the paper. To improve curl we can adjust "jet" speed in small increments.*

3. *Board and label laminates should be evaluated by comparing the properties of their layers by measuring the CME of free dried samples.*

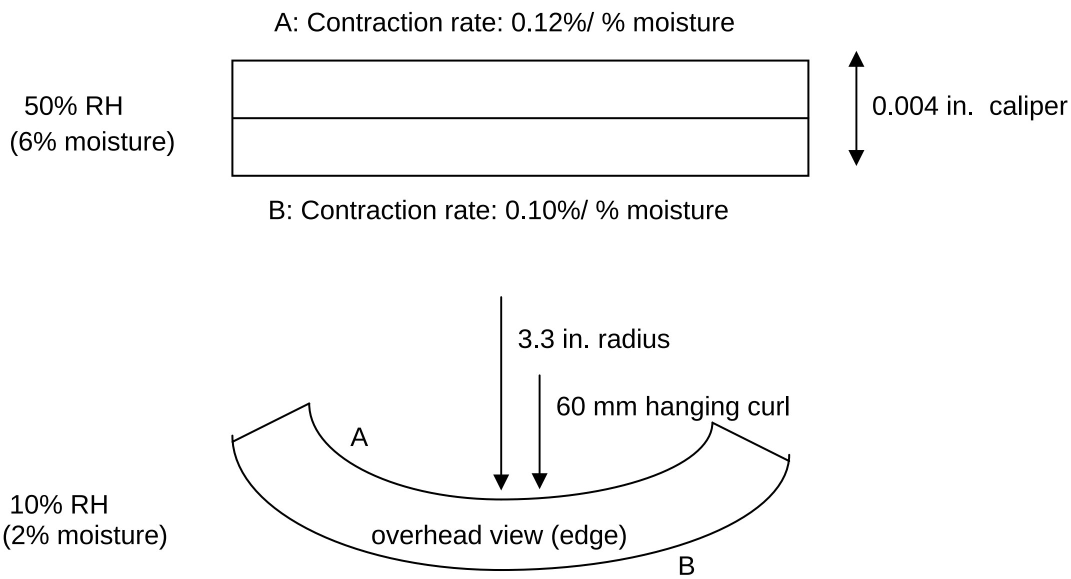
4. *Xerographic curl will be toward the printed side at low moisture, while at high moisture curl will be away from the printed side. Important factors include wire versus felt fiber orientation and built in (internal) strains, which are a result of draw and felt tensions.*

5. *Curl reduction and control include lowering the inherent CME of pulps, reducing refining, adjusting the stock to wire speed to be more equal, and adjusting top to bottom drying.*

6. *If coatings are used, a balancing of wire to felt side binder coat weight is important.*

Basically curl occurs when layers within a sheet expand or contract unevenly when they originally started out at equal length. Uneven shrinkage (or expansion) produces a bending moment because of uneven shear forces. The simplest situation is that a sheet is made up of two layers of equal thickness. In fig. 1 there is a layer A, which contracts at the rate of 0.12% for each percent of moisture loss. Layer B contracts at the rate of 0.1% for each percent moisture loss. In losing 4% moisture, surface A contracts 0.48%, while surface B contracts 0.4%. Without applying an opposing bending moment, the sheet will curl toward surface A. In this case the curl radius formed is about 3.3 inches. (Some assumptions are that there are no other outside forces such as gravity and the elastic modulus of both layers are nearly the same.)

Figure 1. Curl from humidity changes (edge view)



CAUSES OF DIFFERENTIAL CONTRACTION (OR EXPANSION)

Differential contractions can result from

1. A difference in fiber orientation between the two layers.
2. A difference in composition. For example, fines, filler and coatings.
3. Bending a sheet about a small radius.
4. Passing a sheet through a xerographic copy machine fuser

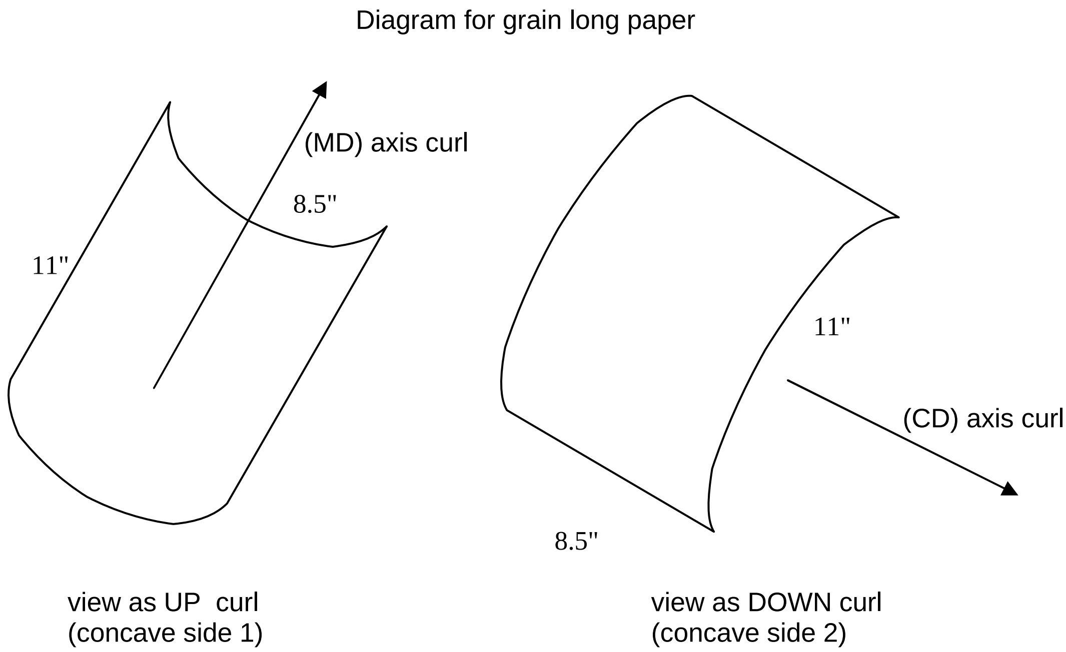
Sometimes several of these are combined to produce curl. The first three can affect copy machine curl also.

DIFFERENTIAL FIBER ORIENTATION

Perhaps the most frequently encountered problem is that of differential fiber orientation. A difference in orientation develops as the result of velocity differences between the forming fabric and the slurry forming the paper. To improve curl we can adjust "jet" speed in small increments of 10-20fpm, at the same wire speed. After an adjustment is made, curl is measured. This procedure is repeated to obtain a jet speed that produces minimum curl (whatever curl measurement is used). *A more fundamental approach would be to measure coefficient of moisture expansion (CME) or tensile stiffness index (TSI) of sheets that have been split in thickness* (appendix A).

A characteristic of differential fiber orientation is the "dual" curl behavior that may be seen in these papers. Such a behavior is illustrated in fig. 2. *MD axis curl to the wire side would occur when fibers are more oriented on the wire side.*

Figure 2 Bimodal curl diagram



MULTILAYERED PRODUCTS

Products such as board and label laminates should be evaluated by comparing the properties of their layers. In board, each layer may have different inherent CME characteristics and different fiber orientations. Any differences in CME between the layers would contribute to curl. *Generally, these layers should be evaluated by measuring CME of free dried samples. To minimize curl, CME values should match each other as closely as possible.*

In label laminates each laminate is made separately, with it own characteristic CME values. The CME of each sheet in the laminate should be as close to the other layer as possible. The amount of shrinkage of each layer produced by wetting and free drying may also be a factor in copy machine labels.

XEROGRAPHIC COPY CURL

The xerographic fusing process can have all of the following taking place: differential heating, strain release or differential strain release, bending, and reversible dimensional changes. ***At low moisture, (75 gsm) paper curl will be toward the printed side, while at high moisture curl will be away from the printed side.***

Other paper variables that affect xerographic curl are wire to felt fiber orientation, wire to felt side moisture and thermal diffusivity, average internal strain and basis weight. For 75 gsm. paper moisture content may be the most significant variable. If paper moisture content is controlled to a consistent low level of 4-4.8%, we probably will not encounter any away from print curl for most, if not all papers.

The other factors become the important ones to control. Wire to felt side fiber orientation should be balanced so they are nearly equal (higher wire side orientation tends to produce MDWS curl at low moisture). The optimum balance will depend on which xerographic machine the paper is used in. To prevent CD axis curl to the wire side, when the wire side is printed first, the wire side perhaps should be slightly more oriented. This tends to produce MD axis curl to the wire side. MD axis curl is easier to stack than CD axis curl, an important consideration in automatic duplex printing.

Lower internal strain levels should reduce the amount of strain release induced curl. Paper made with high drying tensions and high felt tensions have more internal strain and the paper surface touching the hot fuser roll will tend to shrink more compared to the unheated side causing curl to the heated side.

CURL REDUCTION AND CONTROL

This section will describe approaches to controlling and reducing curl. A normal situation is that there is a manufacturing system already being used and we would like to know how curl can be reduced or eliminated. The system may include all of the following:

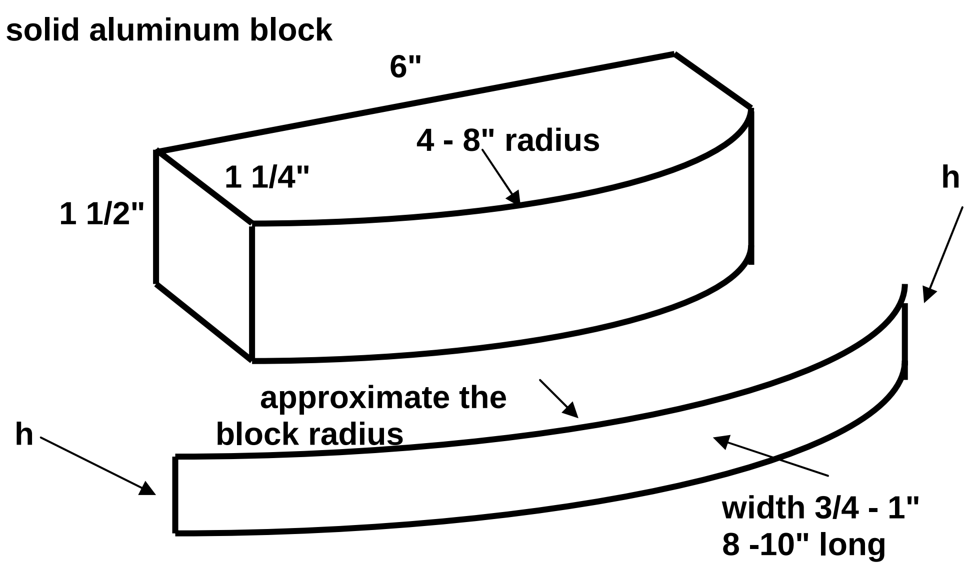
Furnish and stock preparation

Some actions we can take include choosing pulps with lower inherent CME and reducing refining. The objective is to reduce the inherent moisture expansion as much as possible. ***To measure the effect of pulp and furnish on CME with any reasonable degree of precision with handsheets, it is necessary to dry them without restraining shrinkage*.** After handsheets are removed from the mould with blotters, the sheets are separated from the blotters and dried between other dry blotters without constraining shrinkage. After they have been dried the handsheets can be measured for CME characteristics or tensile stiffness index (TSI) is sonic measuring equipment is available.

Wet end

Curl control on a fourdrinier machine involves adjusting the stock velocity relative to that of the wire in increments of 10-20 fpm. We wish to minimize differences in wire versus fiber orientation between wire and felt sides. A measurement that can be used to make comparisons is the ***hot bend curl test*** (see figure 3)

Figure 3. Hot bend curl test



h = hold strip by fingertips and pull against the heated block (300^{o} $\pm$ 10 F.) for 1-2 seconds

Four curls are measured as follows: CD strip WS (or bottom) toward the block
CD strip FS (or top) toward the block
MD strip WS toward the block
MD strip FS toward the block

The optimum is to have the WS strip result equal (or nearly equal) the FS strip for both MD and CD pairs.

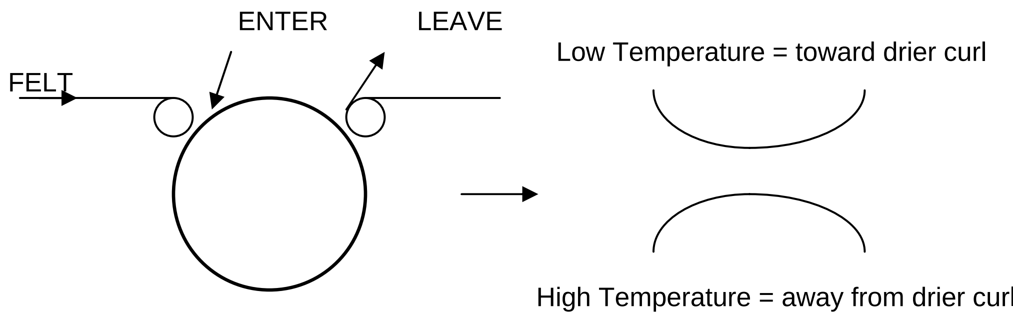
Testing should be done across the width of the machine. If results are different, for example, at the edges of the machine, special adjustments of the flow on the wire need to be made.

Drying

Drying can affect sheet curl of a sheet as it comes off a machine (wet end adjustments should be made first, to reduce this effect). Experiments on a small laboratory dryer have shown some interesting results.

Sheets of previously made paper were wetted and were held against the dryer by a felt as shown in fig. 3. The output curl at lower temperatures was toward the drier surface and at higher temperatures away from the drier surface.

Figure 3. Drying experiment schematic



A drying condition important to xerographic and offset processes is the restraint of shrinkage*. The less a sheet shrinks, the more internal strain is developed* (but it can be limited by using a furnish with lower shrinkage, e.g. lower free dried CME). Lower internal strain will tend to reduce toward print xerographic curl at low moisture and away from print curl at high moisture. In addition, low internal strain will reduce the effect of one side release of internal strain in offset printing. This would reduce curl toward the printed side after the paper has been dried.

Size press or coater

To improve curl by sizing or coating we try to balance the amount of hydrophilic binder between the two surfaces. With surface sizing it would be a matter of balancing the amount of pickup on each surface. With C1S stock, the problem may be attacked by applying a coating of binder on the opposite surface in an amount that equals binder coat weight on the other surface. For C2S papers, a balance in hydrophilic binder applied to each surface is a key factor. From coating weights and binder percentage, we can calculate the amount of binder being applied to each surface.

Appendix A. Split Sheet Measurements

In this example, the change in length is measured on MD and CD strips of WS and FS split sheets between low and high RH.

Split sheet example: low RH: 20%; high RH: 80%(nominal length: 5”)
(moisture expansion measurements)

		MD	CD
length change:	WS	25	54
(in mils)	FS	29	52

calculations:	ratio	angle to CD	angle to MD
WS CD/MD	2.15	65.16	24.84
FS CD/MD	1.79	60.85	29.15

Δ fiber angle estimate 4.31^{o} (positive for WS more MD oriented) (should be nearly the same)
WS/FS ratio 1.20 (i.e. 2.17/1.79) (should be close to 1)

A calculation can be made of a fiber angle difference between the wire side and felt side or a WS/FS orientation ratio can be calculated. When sonic modulus is used, we can calculate a WS/FS ratio (calculation is made using MD/CD ratios of the wire and felt sides). Paper can have Δ fiber angles as high as 7 (+ or -) or WS/FS ratios of 0.7 to 1.4. Satisfactory values are around 1.0 (+ or -) Δ fiber angles or a 1.0 WS/FS ratio.

Appendix B. Other writings on curl (by author)

Published material

CURL PROPERTIES OF PAPER STRUCTURES, Ind. Eng. Chem. Prod. Res. Dev. 20 147-150 1981

DIMENSIONAL PROPERTIES OF PAPER STRUCTURES, Ind. Eng. Chem. Prod. Res. Dev. 20 151-158 1981

CURL, EXPANSIVITY AND DIMENSIONAL STABILITY, Handbook of Physical and Mechanical Testing, vol. 2, 429-443 (Richard Mark, ed.) Mercel Dekker (1984)