Preferred citation: P. Viitaharju and K. Niskanen. Diagonal Curl in thin papers – prepared contribution. In **Products of Papermaking**, *Trans. of the Xth Fund. Res. Symp. Oxford, 1993*, (C.F. Baker, ed.), pp 1501–1510, FRC, Manchester, 2018. DOI: 10.15376/frc.1993.3.1501.

DIAGONAL CURL IN THIN PAPERS

Prepared contribution by
P Viitaharju & K Niskanen

What is diagonal or chiral curl? In figure 1 it is a stack of 10 newsprint sheets dried in an oven. The direction of curl defined by the direction of the 'valley' is oriented clockwise from MD. This is the right handed chiral or diagonal curl. From the cross machine direction, the direction of the valley is counter clockwise. If the stack were dried upside-down, we would have got the same picture. This means that the chiral curl is always going in the same direction that is clockwise from MD. In this presentation we will show you that this is the case almost without exception in thin papers.

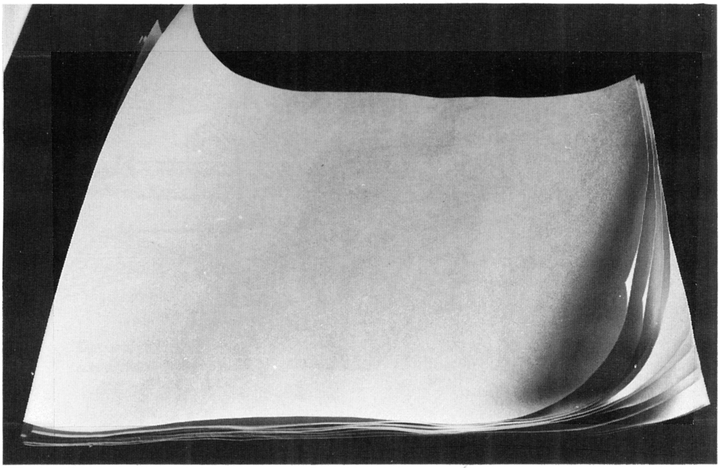

Figure 1: Oven dried (10 min, 103°C) stack of 10 newsprint sheets (15 x 15 cm²) with positive diagonal curl $K_{xy}>0$.

Why does this right handed chiral curl occur? In a couple of articles Dr Gray [1,2] has proposed that the chiral twist in newsprint strips is caused by the helical microsfibril structure of fibres. In the main S2 layer the fibril angle is 0°-30°, figure 2, and apparently the microfibrillar helix is always right-handed in wood fibres. On wetting, wood fibres twist in a counter-clockwise direction. On drying, the opposite takes place. We think that microfibrils dominate the diagonal curl in thin papers.

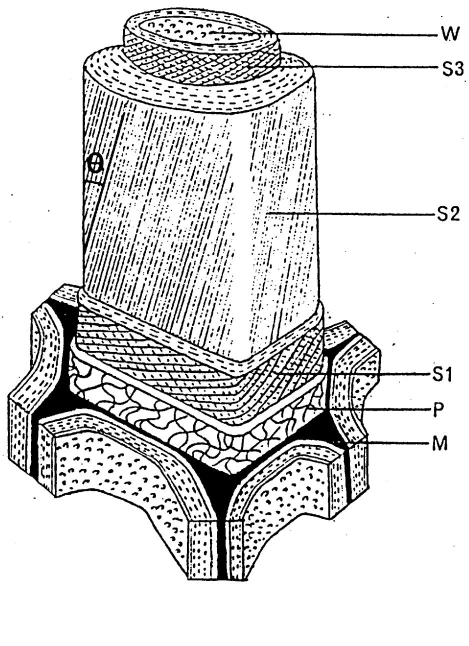

Figure 2: The structure of woodfiber [Ilvessalo-Pfaffli, KCL Internal Report (1981)]

The diagonal curl is a particular form of curl. In a small paper sheet the curvature can be specified using three curl components (figure 3): K_x which is machine direction curl, K_y, which is cross-machine direction curl and K_{xy}, which is twist or diagonal curl. Chiral curl shows up in K_{xy} thus that K_{xy} is always positive and the direction of the cylinder is clockwise from MD in the paper sheet concave upwards. Thus the K_{xy} is the most important curl component in this study. Our coordinate system differs from that to be adopted in the coming ISO standard on curl. According to that standard the sign of K_{xy} would be opposite, ie negative in the cases discussed here.

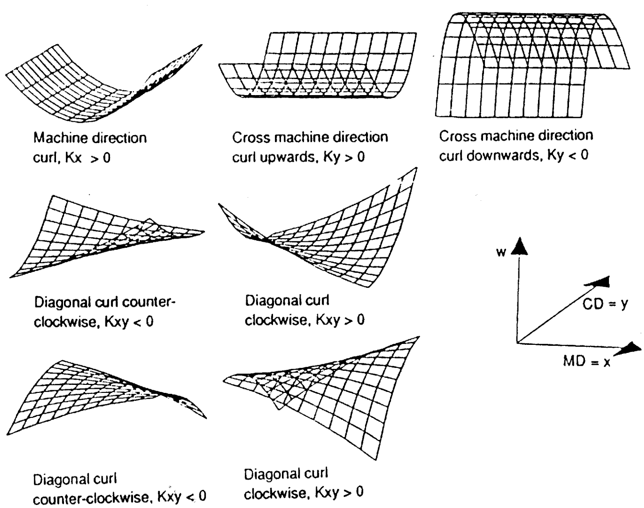

Figure 3: The curl components

Paper curl was measured using a PC-controlled optical instrument, Opticum developed at KCL, figure 4. The shadow cast by the edge of a specimen disc, which diameter is 90mm, is measured with a row detector. The specimen is attached through its centre to the end of rotating rod axis and the curl components K_x, K_y and K_{xy} are calculated from the shadow length that is recorded as a function of the specimen orientation.

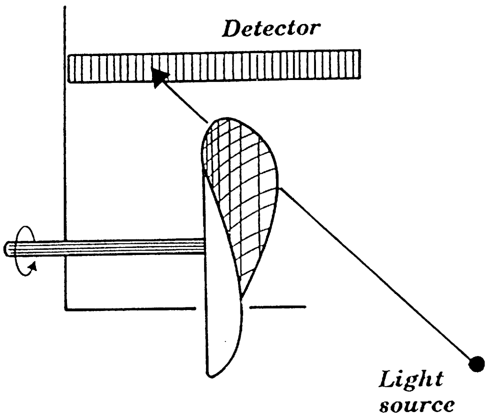

Figure 4: Measurement geometry of the 'Opticum' curl meter

Having measured tens of paper webs with Opticum, we have learned that the CD profiles of curl components are generally more irregular in thin papers than in thick papers. An example of the filtered profiles is shown in figure 5.

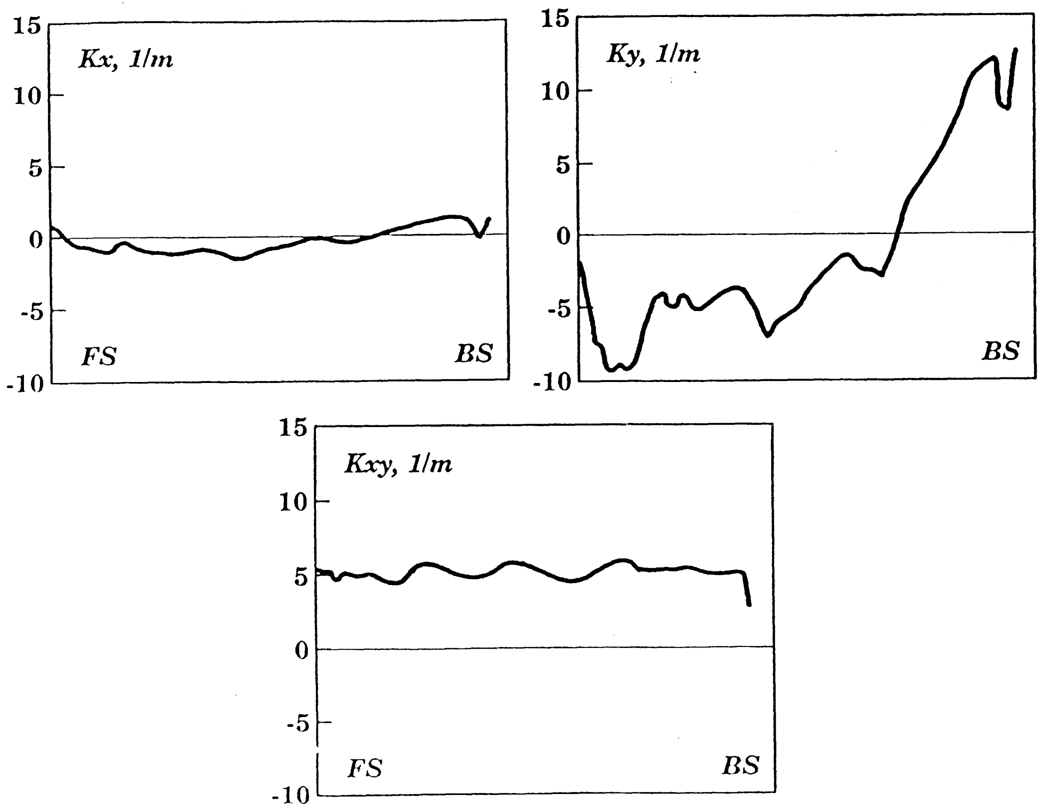

Figure 5: Machine direction, cross-machine direction and diagonal curl, K_x, K_y and K_{xy} at RH=10%, across an 8 m wide commercial newsprint web. Raw data filtered with a floating mean over 1 m.

In spite of the variability of the curl components, the diagonal curl was seldom negative anywhere in the thin paper webs. The sample material consisted of 21 full-width paper webs taken from the standard production of commercial paper machines, (table 1). Out of these 10 were newsprints, 4 SC base papers and 3 LWC base papers all from different machines. In addition 4 kraft-furnish offset printing papers of different basis weights came from one machine. In spite of the variability of curl components, the diagonal curl, measured at relative moisture of 10% was seldom negative anywhere in the thin paper webs.

	Basis weight (g/m^2)	$\langle K_{xv} \rangle$ 1/m	K_{xv} max 1/m	K_{xv} min 1/m	$\langle K_v \rangle$ 1/m
Newsprint	37.0	5.0	7.9	2.2	1.5
	45.0	3.5	8.4	-1.3	22.2
	45.0	8.5	10.5	7.0	-19.4
	45.0	5.8	8.8	3.7	-7.1
	45.0	9.8	16.1	5.8	19.1
	45.0	5.5	7.3	3.0	-15.5
	45.0	8.0	13.0	3.0	-15.9
	48.0	4.0	8.1	2.2	-5.6
	48.5	3.2	12.9	-0.5	-0.5
	48.8	3.9	7.4	1.0	1.0
SC base paper	48.8	5.8	9.2	1.1	-17.0
	52.0	6.7	12.2	-3.0	-25.7
	56.0	4.1	7.9	0.6	-0.1
	60.0	10.7	19.3	5.1	-21.2
LWC base paper	38.0	1.7	3.5	-0.5	6.1
	39.0	2.7	10.3	-1.5	4.8
	39.5	2.8	5.1	-0.4	-1.5
Kraft offset	31.0	3.1	5.1	1.3	1.1
	40.0	13.4	18.1	5.7	-15.1
	45.0	1.3	6.5	-0.9	-12.4
	50.0	3.4	8.3	1.3	-9.1

Table 1: Sample material

So far we haven't encountered a single example in which a low basis weight, this means below 50 g/m², paper web had a negative average diagonal curl K_{xy}. In contrast, at higher basis weights such examples are not difficult to find.

It is a generally accepted fact that the diagonal curl of paper or board should be controlled by two-sidedness in the fibre orientation angle. However, there is no reason why the two sidedness in the orientation angle should always have the same sign for papers made on many different machines. In the absence of anything better, we assume that the ultrasonically measured angle reflects the probability of non-zero two sidedness in the orientation angle.

The mean values of the diagonal curl measured on the newsprint samples are all positive and large when the elastic ratio measured ultrasonically, is large, figure 6a. On the other hand, the sonic angle is small when elastic modulus ration is large, figure 6b. After all, a high orientation index means, by definition, that the fibres are well aligned in the MD. If K_{xy} were determined by the two-sidedness in the orientation angle, then it should decrease with increasing elastic modulus ration in contrast to the observations. The mean CD component of curl has evidently no connection with elastic modulus ratio, figure 6c. Within this set of samples, cross machine direction curl is governed by the final stages of drying

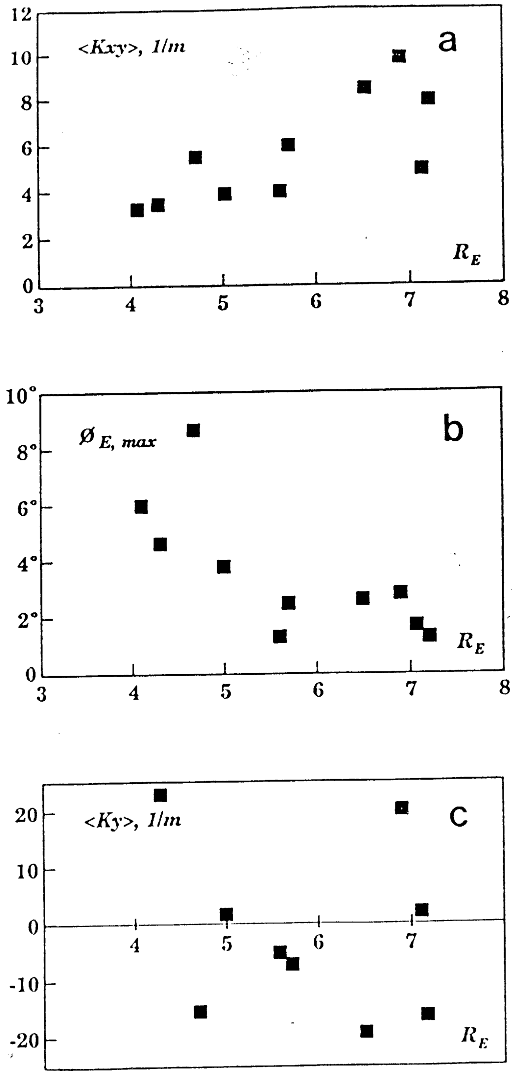

Figure 6: Mean value of diagonal curl, $\langle K_{xy} \rangle$ (a), largest absolute value of sonic angle, $\Phi_{E,max}$ (b) and mean value of cross-machine direction curl, $\langle K_{xy} \rangle$ (c), against elastic MD/CD ration R_E for the newsprint samples.

When all the samples are plotted together, figure 7, it can be seen that, except for two spurious cases, the linear trend between diagonal curl and elastic modulus ration holds irrespective of the paper grade. Mechanical furnish is thus not necessary for the right-handed chiral curl to appear when paper is dried.

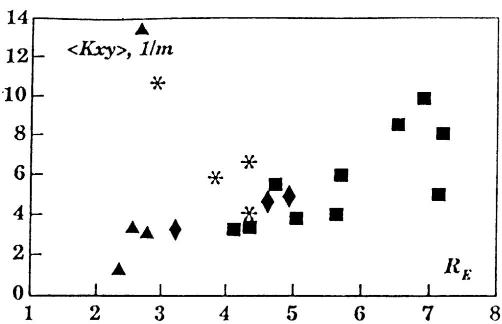

Figure 7: Mean value of diagonal curl $<K_{xy}>$ against elastic MD/CD ratio R_E for the newsprint samples (squares), SC base papers (asterisks), LWC base papers (diamonds) and kraft-furnish papers (triangles).

The effect of paper thickness was not tested in this study. It would be of great interest to know when paper is sufficiently 'thin' for microfibril-induced chiral curl to occur. We found that this is the case, at least at basis weights below 50 g/m². In 'thick' papers or boards, perhaps above 200 g/m², diagonal curl is determined by the two-sidedness in paper structure.

In the intermediate regime of paper thickness, the microfibril-induced chirality competes with the two-sidedness in paper structure and K_{xy} may be positive or negative. It is reasonable that the two effects are additive in K_{xy}.

Conclusions

The microfibril-induced chiral curl, first observed by Gray in narrow newsprint strips, shows up in low basis weight (<50 g/m²) paper sheets of ordinary dimensions irrespective of the paper grade. Thus at low moisture content the diagonal curl K_{xy} is almost always positive in thin papers. Measurements and qualitative analysis suggest that K_{xy} is directly proportional to the degree of fibre orientation and inversely proportional to paper thickness. Apparently, microfibrils dominate the diagonal curl in thin papers and sheet two-sidedness in thick papers or boards.

References

1 Gray, D G; J Pulp Paper Sci, 15(3): J105-109 (1989)

2 Dionne I, Werbowyj R S & Gray D G, J Pulp Paper Sci, 17(4): J123-127 (1991)

This work was supported financially by the Technology Development Centre of Finland.

Transcription of Discussion

CHIRAL CURL IN THIN PAPERS

P H Viitaharju

P T Herdman, Arjo Wiggins R&D Limited, UK

Have you got, in your database, information about which side of the headbox manifold the stock was entering? That can quite often have an effect on the jet angle coming out of the slice and that in turn can affect the fibre orientation and diagonal curl. If you have that data, you might either get a better correlation or explain some of the outlying points.

P H Viitaharju

We have not got that information, but the orientation angle changes from positive to negative across the web or vice versa in these samples. Also the mean value of the orientation angle across the web gets both positive and negative values depending on the machine.

Dr G Baum, James River Corp, USA

I understand that you are using the ultrasonically measured elastic moduli to determine fibre orientation. Do you realise that MD/CD ratio is actually a combination of fibre orientation and any drying restraints in the system? Because of this, measurements of elastic moduli cannot give the fibre orientations.

P H Viitaharju

Yes, I realise that but the elastic modulus ratio used in this study was taken from the middle of the web where drying restraints don't affect so much.

Prof C T J. Dodson, University of Toronto, Canada
If you have no orientation and no drying restraints one of the most striking things to illustrate this kind of geometry is to make in a standard handsheet machine a thick pad of 200-300 gsm. It dries into a beautiful saddle shape, preferring hyperbolic geometry to live in if there are no constraints and no orientation.

P H Viitaharju
Yes, the curling mechanisms in my case and in your case are different.

B Phillips, Shotton Paper Co plc, UK
Thank you very much indeed. That was one of the most illuminating instances of a paper I have certainly seen today, because it explains an awful lot of what happens in my business where we do suffer from curl in newsprint. Could you please recommend where I can get some trees with zero microfibrillar angle in the S2 layer?