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Correspondence

Response to discussion by Stroeven and Hu on paper "The measurement and significance of green sheet properties for the properties of hardened fibre cement"

The author would like to thank Drs. Stroeven and Hu for their useful discussion and comments. Their comments however appear to be based on the assumption that the cellulose fibre in Hatschek made cellulose fibre cement is primarily randomly 2D oriented upon which has been imposed some general orientation. However, this is most likely not the case.

Hatschek made Cellulose Fibre cement sheet consists of multiple thin layers (approximately 0.25–0.4 mm thick) that are plied together to form the sheet. Thus an 8 mm thick sheet will be found to consist of between 24 and 32 layers depending on the specific set-up of the manufacturing plant. Individual cellulose pulp fibres are approximately 2.5 mm long ribbons with widths of around 50 μm and thicknesses of 10 μm or so. Thus there is essentially no orientation of fibres in the sheet Z-direction and the cellulose fibre cement sheets more closely approximates a layed-up oriented short fibre reinforced composite such as may be made from glass fibre and polymer resin.

However, in contrast to manufacture of orientated glass fibre polymer resin composites, the Hatschek process is a dynamic continuous filtration process similar to paper manufacture where a film is formed from a dilute (3% solids by weight or less) slurry of fibres, cement and other ground minerals.[1] The most commonly used production equipment tends to orientate the fibre in the machine direction. Since this would result in product that is weak in the cross machine direction, most Hatschek machines are fitted with fibre orientation devices commonly rotating Archimedean screws that place some of the fibres at an angle to the machine direction. The fibre orientation screws are usually placed at the point where the film is starting to form and because they have limited spatial effect they orientate only the first portion of the fibres to be laid down. This may be seen in Fig. 1, where it is clear that the surface fibres are orientated at about 20–30° to the machine direction which in this case is vertical. There is also a suggestion of fibres oriented in other directions but it is not possible to determine from the photo the entire fibre distribution because this would require measuring the position and depth of each fibre in an opaque material.

Once away from the influence of the screws the orientation of the fibre tends realign with machine direction because the fibres are being deposited from slurry that is stationary relative to the movement of the sieve on which the film is formed.

It would seem that a two phase model of fibre orientation would be more realistic where one phase containing the first laid down fibre is orientated at an angle to the machine direction depending on the screw speed and a second phase comprising the remainder of the fibres is oriented parallel to the machine direction.[2] It is clear of course that there would also be some random component of fibre orientation in both of these proposed phases because the fibres are not straight.

The actual orientation of the fibres has not been determined to the author's knowledge so it is not at this time possible to accurately model failure behaviour of the composites as well as could be desired. However by taking the commentator's approach of the last section of his commentary, but using a model with a proportion of fibres aligned off the machine direction

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[1] "Formation of Films on Overflow Hatschek Machines" A.M. Cooke, 7th Inorganic Bonded Wood Cement Composites Conference, 2002, University of Idaho.

[2] In some machines that are designed to maintain the slurry stationary relative to the motion of the sieve however the second phase would be more likely to be randomly oriented. However in the work presented in the Author's original paper this is not the case.

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to about 20° as seen in the photo we can express the commentator's equations (8) and (9) as

$$\sigma_{f\perp} = 1/2aV_{f2D}\tau_f + aV_{f1D}\tau_f\cos\theta \tag{1}$$

$$\sigma_{f\square} = 1/2aV_{f2D}\tau_f + aV_{f1D}\tau_f\sin\theta \tag{2}$$

where $1/2aV_{f2D}\tau_f$ is the contribution to strength of the 2DIUR fibre, the balance of each equation is the contribution due to the orientated fibre and θ is the angle between the oriented fibres and the machine direction. Assuming that $\mathrm{XR} = \sigma_{f\square}/\sigma_{f\perp}$ is 0.58, we can solve (1) and (2) to show that $V_{f2D} \approx V_{f1D}$. In other words about 50% of the fibres have been aligned at 20° to the machine direction and the remainder are randomly orientated. This is actually surprising but it reflects the author's observation that it is difficult with screw alignment equipment to obtain good cross direction strength. It is instructive to vary the degree of alignment of the overall fibre mass and the angle to which the fibre is placed relative to the machine direction and determine the relative cross direction strength. The following table illustrates

Angle of aligned fibres to machine direction		Ratio and percentage of aligned fibres to 2D IUR fibres				
		0.5	1	2	3	4
		33%	50%	67%	75%	80%
Degrees	Radians	Cross ratio of strengths of final product				
0	0	50.0%	33.3%	20.0%	14.3%	11.1%
10	0.174533	59.1%	45.4%	34.3%	29.6%	26.9%
20	0.349066	69.2%	58.5%	49.8%	46.0%	43.9%
30	0.523599	80.4%	73.2%	67.2%	64.6%	63.1%
40	0.698132	93.0%	90.3%	87.9%	86.8%	86.2%
45	0.785398	100.0%	100.0%	100.0%	100.0%	100.0%

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Fig. 1. Fibre alignment on the surface of a Hatschek made fibre cement.

The table shows as would be expected that increasing the angle of the aligned fibres relative to the machine direction improves the ratio of cross direction to machine direction strength (XR). As would be expected when the angle of the oriented fibre reaches 45° to the machine direction then XR reaches 100% irrespective of the ratio of aligned to random fibres. What is somewhat unexpected although logical when thought through is that it is detrimental to the development of cross direction strength to increase the amount of fibre that is aligned compared to 2DIUR. This should be expected since aligning some of the fibres reduces the amount of 2DIUR fibres remaining. Since this is contrary to normal experience we may conclude that the distribution of the other than aligned fibre may not be 2DIUR as modelled and that it more likely is preferentially aligned towards the machine direction. Determination of the actual distribution of the fibre would therefore be extremely instructive for modelling the strengths of these sheets.

The author would once again like to thank the commentators for a stimulating and productive discussion of the issues and for pointing out the way to further progress in the understanding of the operation of Hatschek machinery.

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