Project Title: Wet Fiber Deformability for Paper, Board, Tissue and Towel

GT Project Staff:
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PROGRAM OBJECTIVE:

The ability of pulp fibers to deform into a well bonded network controls the extent to which physical and optical properties of a paper sheet can be realized. Research into the deformation behavior of pulp fibers has generally focused on the flexibility, conformability, compactability, and collapsibility of lignocellulosic fibers. All types of deformation are interrelated and contribute to sheet consolidation and/or the formation of fiber bonds. However, the controlling mechanism for each is not necessarily the same. Recent fiber-fiber imaging techniques developed in Ragauskas' laboratory have provided the experimental ability to directly measure, for the first time, the geometry of single fiber crossings (i.e., stepheight and freespan) was determined using light interference and an image analysis computer program.[1] This project is directed at employing this methodology to evaluate fiber deformability of several key virgin and recycled grades, and determine how wet-end chemicals and fiber engineering can influence this key papermaking parameter, and to understand the transitions which occur in going from the wet to the dry state. This industry directed program addresses a key research need of the Pulp and Paper Industry, as described in the Agenda 2020 Technology Platform. The results of this study will address the industry's need to utilize pulp fibers for higher value products and will lead to breakthrough papermaking technologies.

PROJECT BACKGROUND:

As discussed, fiber deformation behavior contributes to key physical and optical properties. Fiber-fiber freespans in this program were measured along the central axis of each fiber and stepheights were determined by analyzing the interference fringe pattern, these experimental protocols were reported earlier by Lowe et al.[1] Figure 1 illustrates the stepheight (S) and the freespan (F) of a fiber crossing. Average values of freespan and stepheight were calculated for each set of conditions.

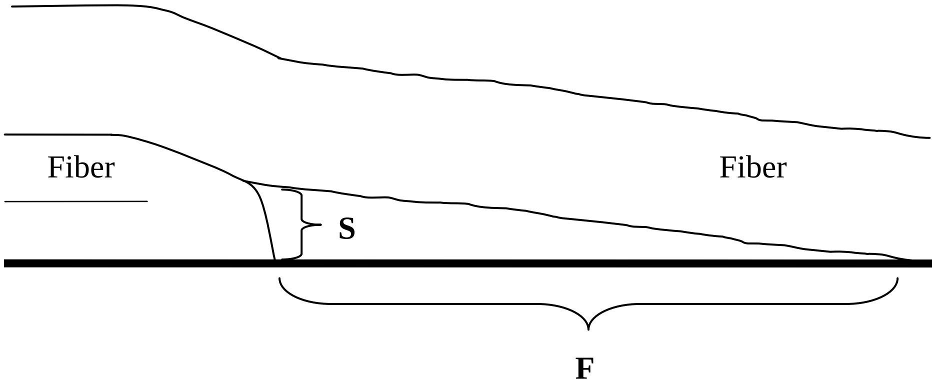

Figure 1. An illustration of the geometry of a fiber crossing showing the stepheight (S) and the freespan (F).

The effect of refining. Figure 2 provides several representative micrographs employed for our measurements. Each micrograph was analyzed for stepheight and freespan measurements, and the results for unbleached hardwood are shown in Figure 3. The data scatter is due, in part, to the natural variation in the deformation behavior of pulp fibers. The linear regression analyses pass through the origin, and nearly coincide with each other. Figure 4 shows the average freespan and stepheight response at each refining level for both hardwood and softwood. The ratio of freespan to stepheight remains approximately constant (*e.g.* the data fall along a single line through the origin). Since the freespan is not reduced independently of the stepheight, refining only serves to decrease the stepheight of the underlying fiber. There is no indication that refining reduces the freespan in a fiber crossing by increasing fiber flexibility. Therefore, a major effect of PFI refining on deformation behavior for the hardwood kraft pulp is to make the fibers more collapsible leading to reduced stepheights. This is similar to the response we reported for a softwood kraft pulp[1] and is therefore relatively insensitive to fiber length.

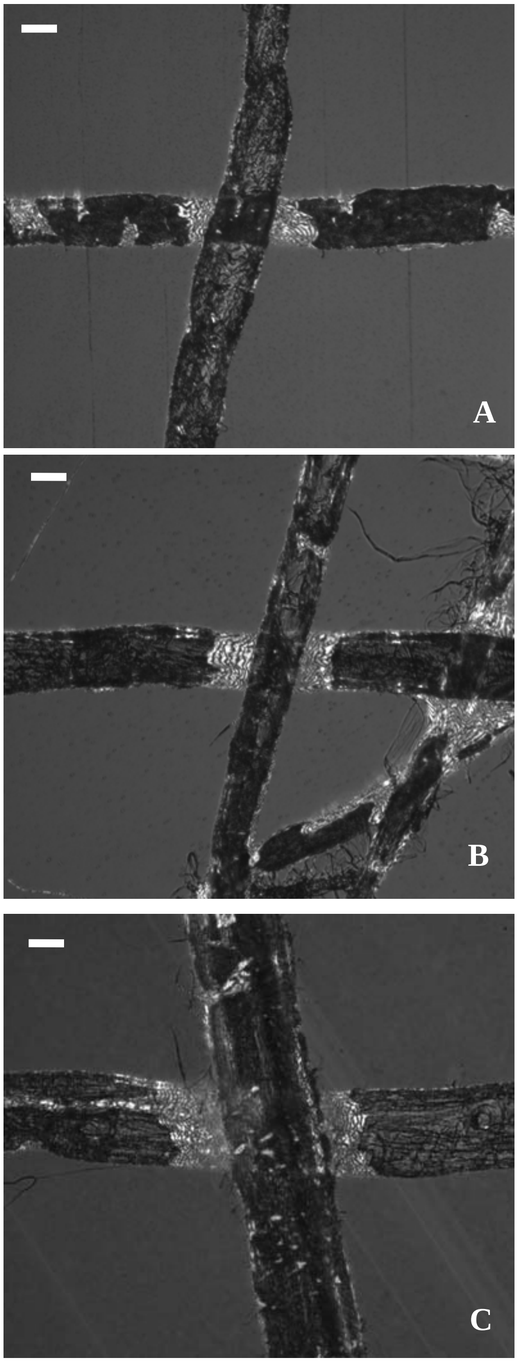

Figure 2. Representative micrographs of bleached hardwood (A), unbleached hardwood (B), and unbleached softwood fibers (C). The bar is 15 μm.

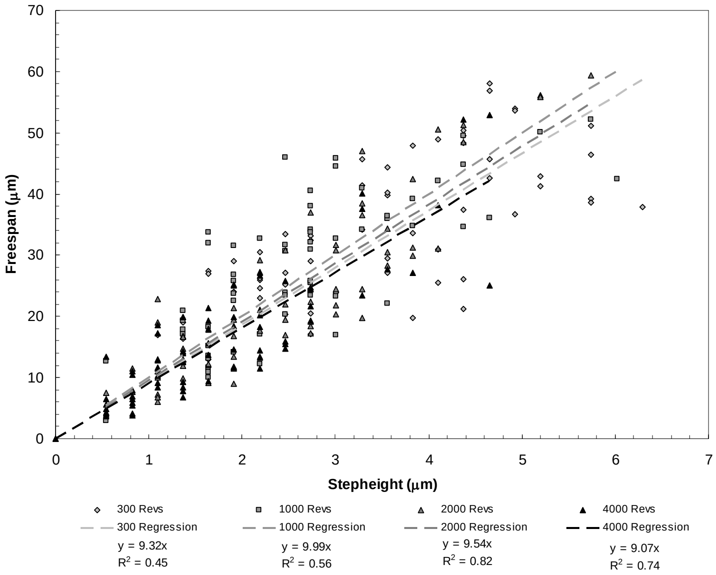

Figure 3: The effect of refining for unbleached kraft hardwood fibers. Each refining level is shown as well as the linear regression analysis.

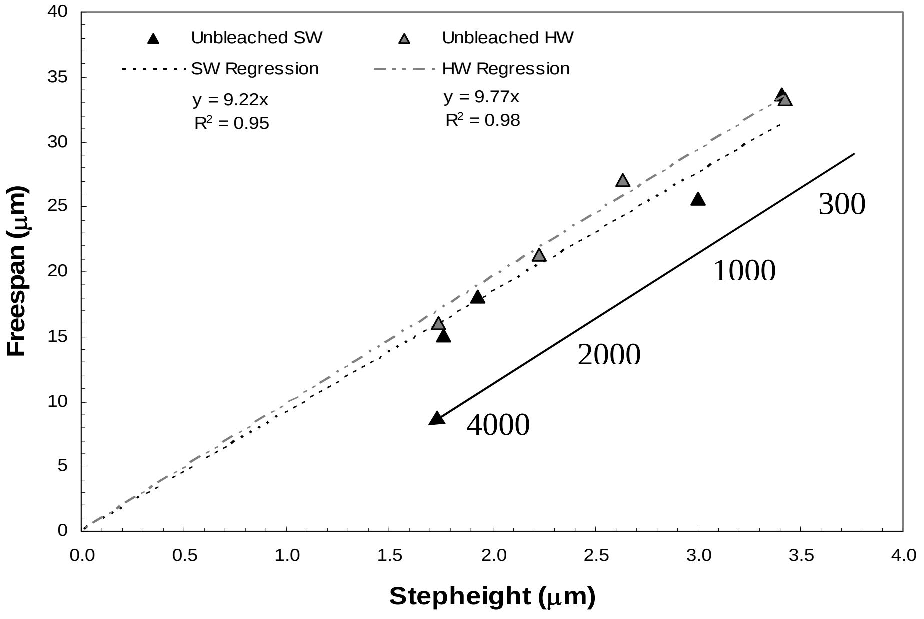

Figure 4. Average freespan versus stepheight for refined unbleached softwood and hardwood pulps. The regression analysis is shown, as well as the effect of refining level.

It should be noted that with increased refining the stepheights drop lower than one would expect. The cell wall thickness can range from 2.0-4.0 μm which should lead to stepheights of at least 4.0 μm. On several occasions, stepheights of less than 2.0 μm were measured. Lowe et al.[1] described a similar phenomenon and stated that the underlying fiber is most likely deforming. These results suggest that the cell wall may deform more readily that previously thought, and this deformation behavior is increased with PFI refining. Nanko and Ohsawa[2] have also reported that the cell wall may possess some fluidity which is consistent with our data. The increased deformability allows fibers to assume a lens shape which effectively reduces the stepheight of a fiber crossing. Lens shaped fibers have been reported in many articles dealing with paper cross sections.[3]

Figure 5 shows a comparison between unbleached and bleached never dried hardwood fibers. While the stepheights stay virtually the same, reduced freespans at each refining level lower the ratio of freespan to stepheight (i.e. the slope of the regression line is reduced). This is in agreement with work from other researchers. It has been shown that never dried pulps have almost no fiber collapse prior to wet pressing.[4] Also, there is very little difference (~3%) between the transverse elastic modulus of low yield unbleached and fully bleached kraft pulps.[5] Therefore, it was anticipated that two uncollapsed pulps with similar coarseness values and a similar transverse elastic modulus would exhibit a comparable amount of fiber collapse with increased refining. Paavilainen has shown that bleached fibers have higher wet fiber flexibility; hence, bleached fibers will have shorter freespans.[6]

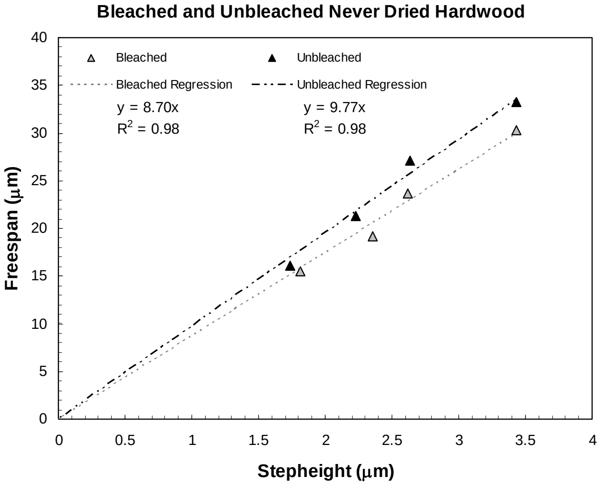

Figure 5. Average freespan versus stepheight for unbleached and bleached never dried hardwood pulps. The regression analysis for each set is also shown.

These results and others taken together are unanticipated. A constant stepheight/freespan ratio implies that the flexibility of the overlying fiber is largely irrelevant to the formation of fiber crossings. Sheets are densified by pressing or drying via a change in the stepheight of the underlying fiber.

In the dry state the ratio of stepheight to freespan is constant regardless of pulp species, refining, bleaching, pulp drying, and wet pressing. All of the stepheight versus freespan plots are straight lines through the origin which current theoretical models can not explain. Bending as the controlling mode of deformation has been previously been dismissed.[7] While it has been shown that the deformation of the freespan is likely controlled by shear, it has not yet been demonstrated that the deflection of the freespan is controlled by shear modulus. An extension of the equations developed by Waterhouse and Page for pure shear to a wet fiber crossing leads to Equation 1. Where *d* is the deflection or stepheight, q is the fiber distributed load, L is the freespan, G_{13} is the shear modulus of the fiber, and A is the cross-sectional area. .

Eqn.1 $$d = \frac{qL^2 f_s}{2G_{13}A}$$

For shear modulus to control the deflection, the stepheight should be proportional to the freespan squared which has not been observed. Since neither bending nor shear is controlling the deflection of the freespan, additional factors must be involved in the observed effects. It should be noted that the predictions of Waterhouse and Page[7] are for the wet state and the measurements reported here are for the dry state. It is certainly possible that the deformation behavior in the wet state is ultimately of no consequence to what happens in the dry state, but further work is needed to determine whether this supposition is correct

In summary, a new method to investigate the deformation behavior of single fiber crossings has been developed. Employing dyed pulp fibers pressed onto glass slides and micrographs were acquired. Freespans and stepheights are readily measured to determine the effects of refining, wet pressing, drying and bleaching on the fiber deformability of unbleached never dried, bleached never dried, and bleached market pulps.

The main effect of refining was to reduce the stepheight in the fiber crossing for both bleached and unbleached fibers by increasing the tendency of the cell wall to collapse and deform. All the pulps and treatments investigated maintained a relatively constant value for the ratio of stepheight to freespan at least as seen in the dry state. This result is quite unexpected and suggests the deformation behavior of cellulose pulp fibers may be more universal than previously thought.

OVERALL PROGRAM DELIVERABLES:

Research activities for this program we determine the influence of fiber deformability in fiber-fiber bonding for three important grades of paper including: (1) HW/SW kraft tissue pulp; (2) southern SW kraft linerboard and (3) ECF bleached kraft copy paper both never-dried and dried. The interaction of these furnishes with carboxylmethyl cellulose and cationic starch will also be examined to document how papermaking additives influence fiber-fiber deformability. At the completion of this project, program sponsors will receive a final report that highlights how fiber-fiber deformability impact these three key fiber resources and the role that wet-end chemicals play.

VALUE OF DELIVERABLES:

As discussed previously, fiber-deformability is a key parameter influencing physical and optical properties of paper. Prior to the methodology developed in Ragauskas laboratory this parameter could not be measured directly. Our technique allows fiber deformations to be measured using conditions that realistically simulate what occurs in a paper sheet. We have already documented unanticipated fiber network properties which have implications for pulp refining and sheet formation. We anticipate that as this methodology is applied to alternative pulps and wet-end chemicals new knowledge will be acquired that will facilitate the development of new papermaking technologies and wet-end chemicals.

PROJECT GOALS:

The proposed study will provide fundamental information as to how fiber deformation in a fiber network is influenced by fiber resource, refining and papermaking chemicals. This information will be utilized by its sponsors to optimize physical strength properties of paper, board and tissue.

PROJECT APPROACH:

The researchers will work with a program sponsors to secure refined and unrefined (1) SW/HW bleached kraft tissue fibers; (2) southern SW linerboard and (3) ECF bleached SW kraft for copy paper grade. The deformability of these fibers will be examined for dried and never-dried fibers. The key research tasks include,
Tasks:

1. Evaluate the performance of fiber deformability for refined and unrefined SW/HW tissue pulp
2. Evaluate the performance of southern SW kraft linerboard and ECF bleached kraft pulp refined and unrefined
3. Correlate deformability results with physical properties of handsheets.
4. The capability of measuring step height and free span in the wet state will be used to better understand the mechanisms involved in transitioning from the wet (wet pressing) to the dry state (conditioned state)

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see Appendix 1

Appendix 1: Lowe, R., Page, D.H., Ragauskas, A. (2005) Imaging fibre deformations. In: Advances in Paper Science and Technology: Transactions of the 13th Fundamental Research Symposium Held at Cambridge. Ed. S. J. I'Anson. FRC, Bury. pp. 921-941.