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MAY/JUNE 2020

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Fiber Modification Technology

A new enzyme-based technology to condition unbleached Kraft fibers has proven very successful

Domtar's Plymouth Mill

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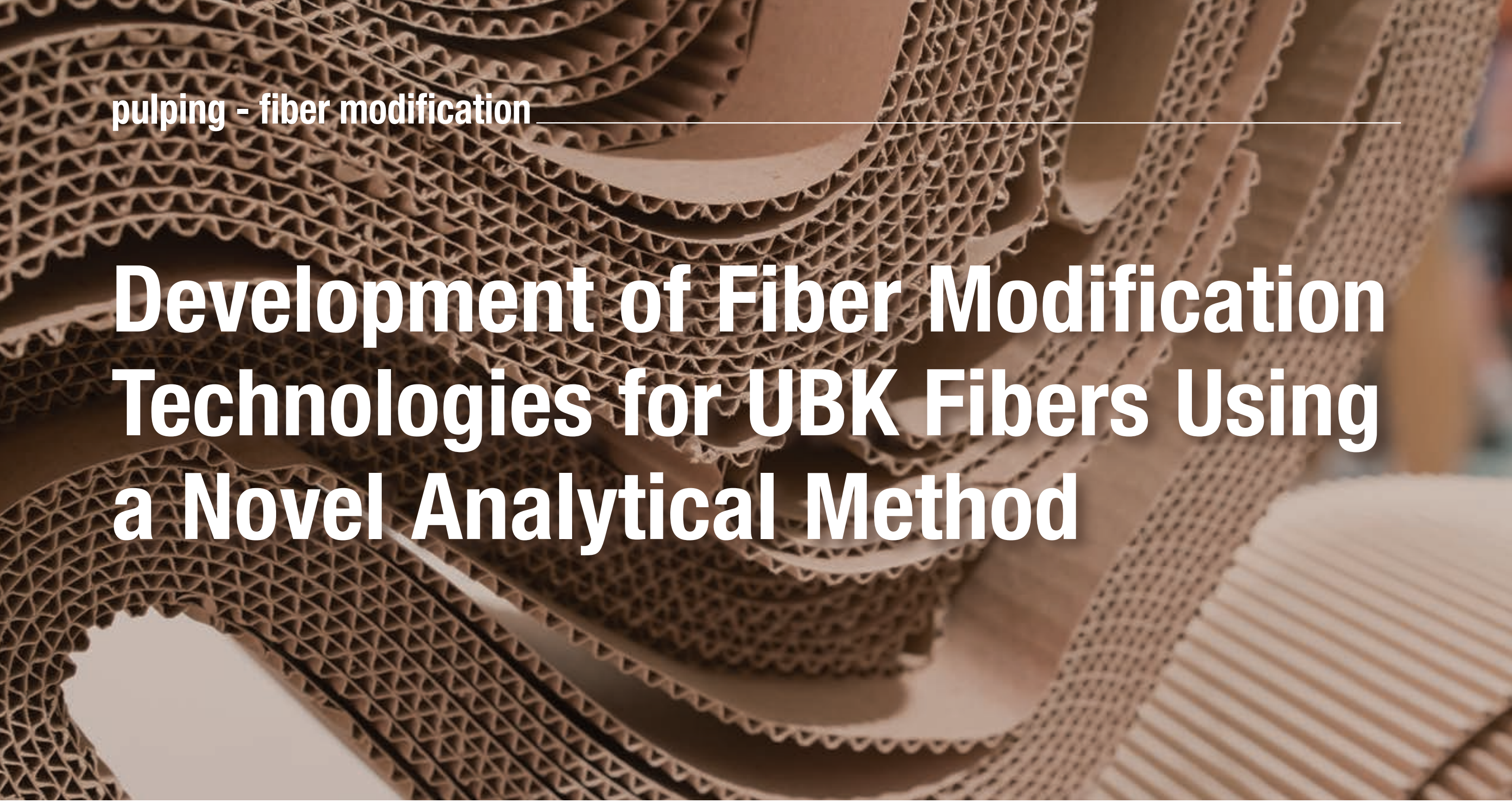


Development of Fiber Modification Technologies for UBK Fibers Using a Novel Analytical Method

The effect of enzymatic treatment to condition fibers prior to refining has been used mostly in bleached and recycled fibers. Although the application of these technologies in unbleached Kraft has been more challenging, a new enzyme-based technology has been developed that has proven to be very effective in unbleached Kraft.

By Rosy Covarrubias, Innovation Director Packaging; and Mark Reed, Group Manager - Biotechnologies; Buckman

In an increasingly competitive market, you must control costs if you want to survive and prosper. The fiber-based packaging industry is striving to remain competitive and profitable while meeting the increasing demands of its customers for stronger and lighter product while replacing plastic-based packaging.

To meet market demands most mills are using costly levers in order to achieve strength targets: using polymeric/starch solutions, adding basis weight, reducing speed, increasing refining and managing fiber quality. These can create unintended consequences in the process, and in many cases, they are vastly overused. Even with all these tools, sometimes mills are unable to meet market demand for quality and strength-to-weight ratio, resulting in rejected or discounted product.

All these strategies work but are used to the point of diminishing return, increasing cost and introducing instability to the process. Some of these approaches also limit your mill's ability to increase production. Some require more chemicals overall, which will impact system stability and cost.

The mechanical treatment of wood pulp fibers is used to impart to them the appropriate characteristics for papermaking. A part of the stock preparation phase of papermaking, refining is the most important aspect of the process. It is here that the characteristics of the cellulose fibers and the composition of the furnish that comprise paper are determined, affecting how the fibers bind with each other during the formation of the paper web and what the various properties of the paper will be.

Enzymes for Fiber Modification

Wood fibers are mainly composed of cellulose and hemicellulose microfibrils encrusted in lignin-carbohydrate matrices. They are multilayered structures that can have internal delamination and external fibrillation after chemical and/or mechanical processing.

Wood pulp can be treated with enzymes, and some of the cellulose in the fiber is hydrolyzed. This biochemical treatment reduces the amount of mechanical treatment needed to reach the desired fiber properties. Less mechanical action and less energy are required. Since refining requires significant energy input, as well as capital investment for equipment, facilitating the refining process provides numerous benefits, including stronger paper, elimination of other chemical additives and reduced energy usage.

Properly applied enzymes can enhance fiber strength, reduce refining time and increase interfiber bonding though fibrillation. The main challenge in using enzymes to enhance fiber bonding is to increase

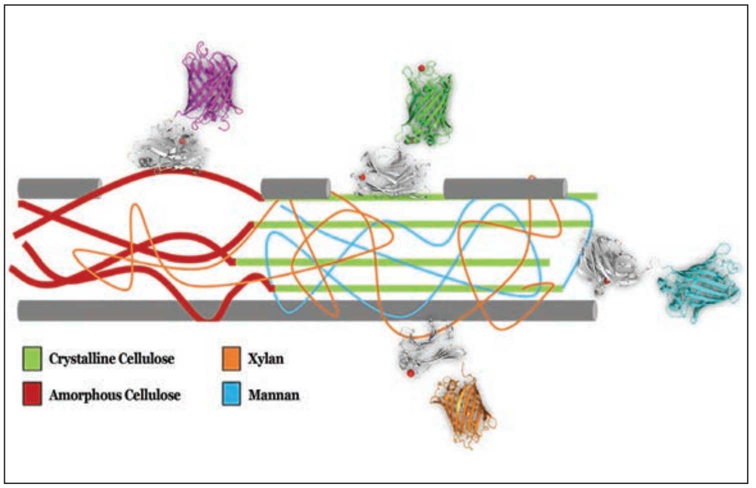


Figure 1. Schematic representation of probe binding to a wood fiber. The left side of the fiber shows a lignin free fiber, where amorphous cellulose dominates (cherry strings). On the right side, the straight green bars represent crystalline cellulose. Hemicelluloses such as xylan (orange) and mannan (blue) are shown as polymers that help keep the fiber together. The probes designed here attach specifically to their respective target polymer, as indicated by the matching color of their fluorescent module (Hebert-Ouellet et al. 2017).

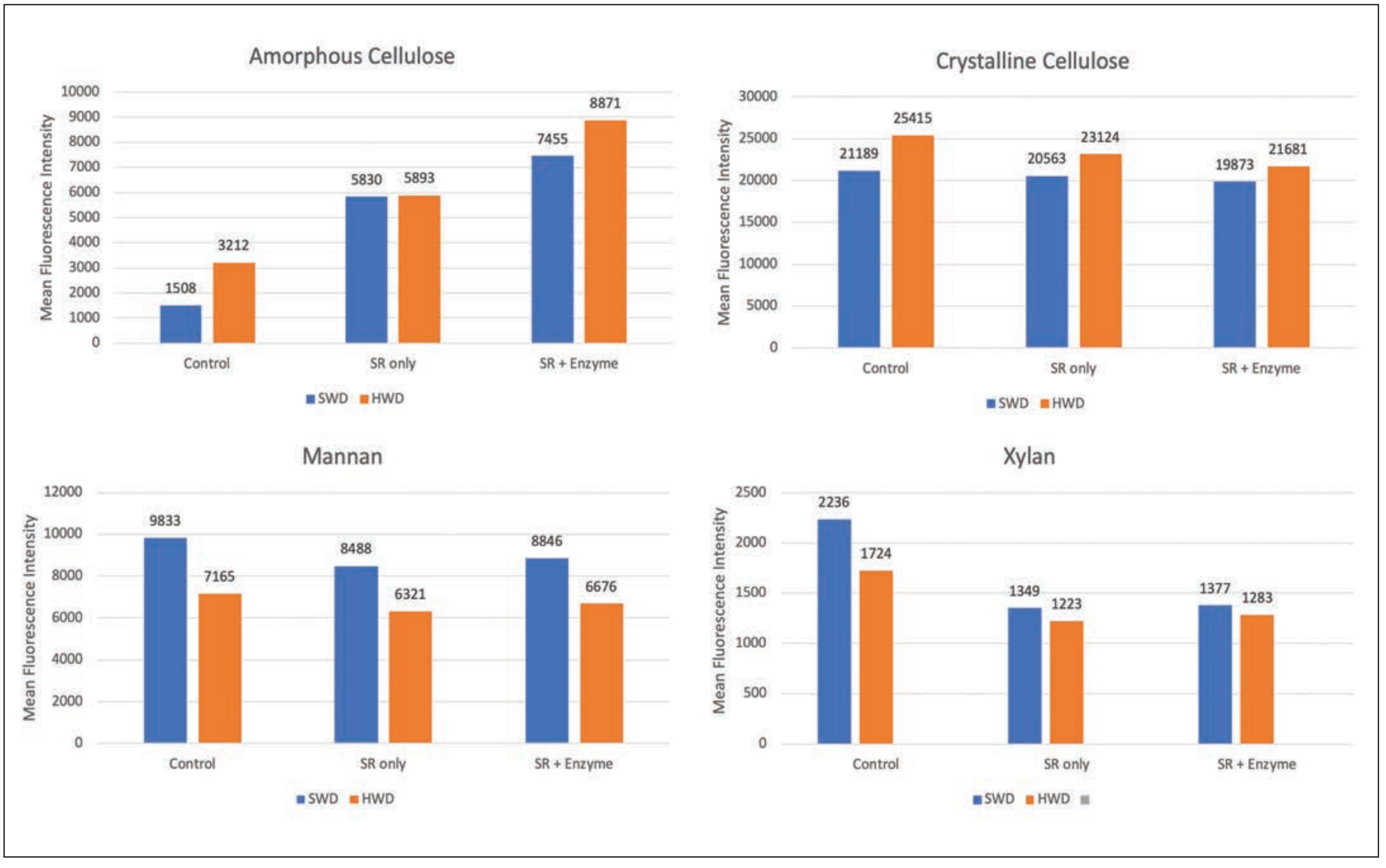


Figure 2: Surface characterization results for the four substrates across three treatment groups on hardwood (HW) and softwood (SW) furnish. A) Amorphous cellulose, B) Crystalline cellulose, C) Mannan and D) Xylan. Values provided represent the mean of at least three samples.

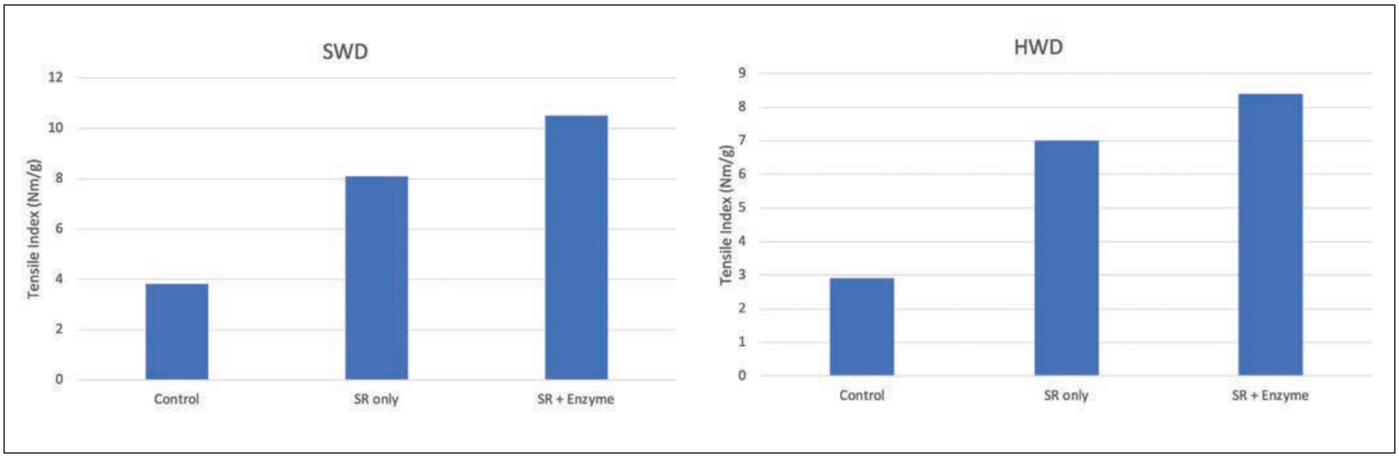
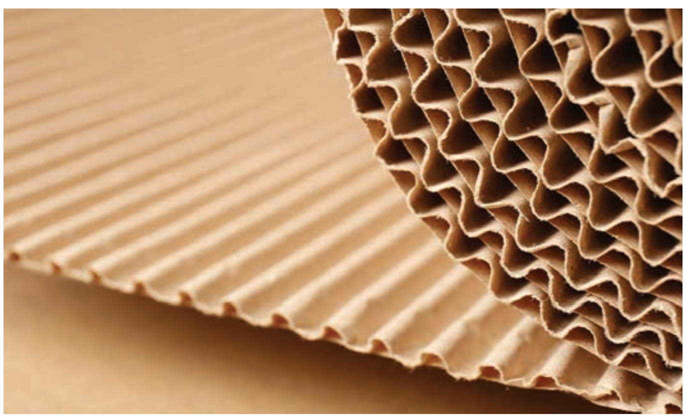


Figure 3: Summary of tensile data. Values provided are the mean of at least seven measurements.

fibrillation. Enzymes used to modify the fiber do on a molecular level what mechanical refining does on a macro level. These enzymes break bonds in the cellulose chain, thus weakening the surface of the fiber and resulting in the same effects,
collapse and fibrillation, that mechanical refining does.

Fiberlytics™: A Novel Characterization Technique

The fiber's physical and surface properties vary based upon the species of the fiber present, the way the fiber was prepared and even the growing conditions and location of the original tree. Currently there are few ways to understand the variability in fiber and how to mitigate the process variation this introduces. In essence, customers are unable to independently validate the quality of the incoming fiber, meaning that the fiber they use today may not be similar to the fiber they used yesterday or the day before that. This can result in significant swings in product quality, runnability and production as operators respond to shifts in fiber property reactively.



Properly applied enzymes can enhance fiber strength, reduce refining time and increase interfiber bonding though fibrillation.

In the last few years, we have focused on developing new screening techniques that can provide a greater understanding of how specific enzymes interact with the different cellulosic fibers and can accelerate the product development phase. This novel characterization technique provides a better understanding of what types of cellulose and hemicellulose are present on the surface of the fiber. This information, combined with the known activities of the enzymes, is critical to enzyme selection.

This new technique has also sped product development efforts resulting in new a product that proved very effective for unbleached Kraft fibers.

Utilizing this fiber surface characterization method in the development phase, it has become possible to select the ratio of enzyme activities to best match the ratio of the substrate. In matching the activity profile to the substrate profile of the fiber itself, it was possible to shortlist the product that was predicted to have the best impact on the final process in a short period of time.

Laboratory Work

Extensive work was done to demonstrate the potential of the fiber surface characterization method, which was first published in 2018. During the development of Maximyze® 777 for unbleached Kraft fibers, representative softwood ("SR") and hardwood ("HW") samples were treated with either a strength resin alone ("SR Only") or with a combination of strength resin and enzyme product ("SR + Enzyme") and compared to untreated fiber **(Figure 2)**. In comparing the levels of amorphous cellulose in the samples, the data showed that levels increased with the addition of strength

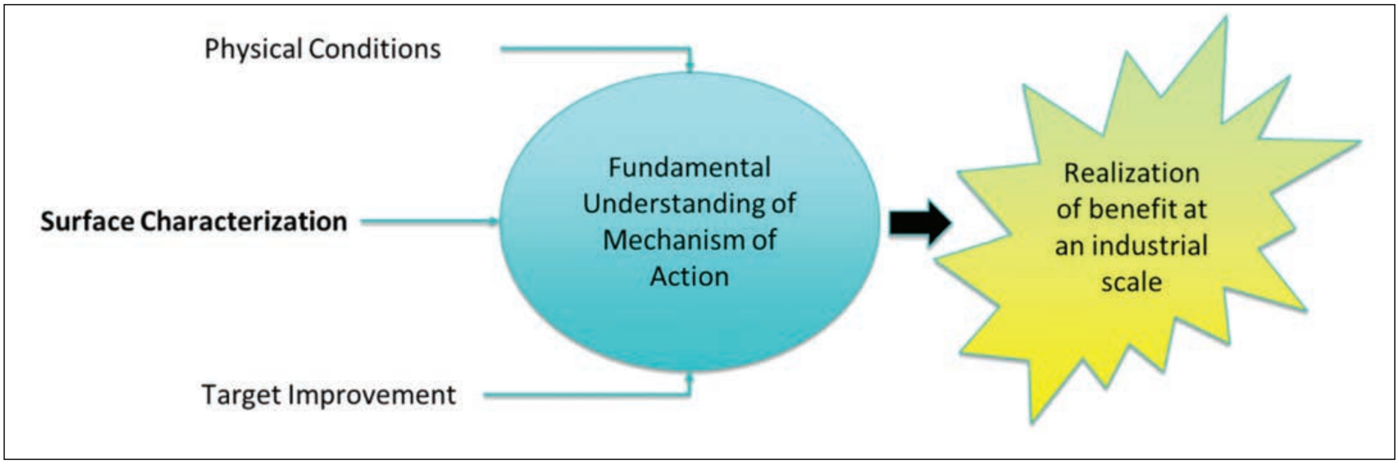


Figure 4: Overview showing how the combination of substrate, operating conditions, target benefit and enzyme can yield beneficial results.

resin, but that a further increase was achieved in the presence of enzyme. The crystalline cellulose signal was seen to decrease between the control and the two treatment groups, with the lowest signal being observed in the enzyme treatment group. Similar levels of decrease were observed in the levels of mannan and xylan. The data is interesting because it showed a change in substrate prevalence even when a non-enzymatic treatment was added. The action of the enzyme is clearly observed in the concurrent increase in amorphous cellulose and decrease in crystalline cellulose.

To further understand how these changes in signal relate to the strength characteristics of the sheet, a handsheet assessment of tensile strength was executed **(Figure 3)**. The data shows that both treatment groups were able to improve the tensile strength significantly versus the untreated control. This result supports the importance of the crystalline: amorphous cellulose ratio (Hebert-Ouellet et al. 2017), as both treatment groups showed a reduction in crystalline signal and an increase in the surface-available amorphous cellulose. Furthermore, the improvement in strength correlated with the trend in ratio between the two treatment groups, supporting that the surface characterization method has predictive power.

In utilizing Fiberlytics™ in the selection of enzymatic products, it becomes possible to select the ratio of enzyme activities to best match the ratio of substrates. In matching the activity profile to the substrate profile of the fiber itself, it was possible to find the best formulation for unbleached Kraft fibers. In combining knowledge of the fiber surface with the activities of the enzymes under specific operating conditions, it now becomes possible to rapidly identify enzymatic technologies that deliver the specific benefit required **(Figure 4)**.

Conclusions

Prior to the development of the new characterization technique, several attempts have been made to develop a product that was highly effective in unbleached Kraft fibers with limited success. In understanding the composition of the fiber surface with respect to substrate, this novel technique provides a unique opportunity to understand the fiber at a level that is relevant to the action of enzymes. The data reinforces that fiber surface characterization is both a useful diagnostic tool to assist in understanding the impact of process change and enzyme selection but also can be used predictively in selecting new enzyme technologies for given applications. ■

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