ENZYMATIC AND MECHANICAL TREATMENT ON CHEMICAL PULP

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ABSTRACT

Effect of fiber treatment with a cellulase-rich enzyme (Liftase A40), and with two refining methods (Valley beater beating and impact refining) on wood fiber and on handsheet properties were investigated at three refining levels (300, 400, and 500ml) for two furnishes (NBKP and LBKP). Parts of the treated furnishes were classified by 150 mesh screen into 'fine-free fiber,' and fines. Fiber length analysis, WRV, zero-span strength, and other handsheet mechanical properties were compared. The study showed that Liftase A40 lowered the zero-span of the furnishes. Pretreatment with Liftase A 40 followed by refining significantly lowered the fiber length and refining energy to reach to the target freeness. Impact refining, which is done by hitting the fibers vertically with rod at 20% solid content, kept the fiber length, increased WRV, and improved handsheet mechanical properties much more than valley beating. Properties of 'fines' from different sources were compared in detail in the study.

INTRODUCTION

Paper physical and mechanical properties largely depend on paper making process, where stock preparation is one of the major property controlling processes. Stock preparation shapes the fibers to be suitable for maximizing target properties and for minimizing process troubles and undesirable properties. Application of enzyme in stock preparation recently became norm in many countries for drainage improvement (1-4), effective deinking (5-6), refining energy saving (7), and even paper strength improvement. Enzymatic treatment of virgin chemical pulp has been studied for last two decades to know what kinds of reactions are involved and how the fiber physical and chemical properties change (8-9). The knowledge from the previous studies with enzymes leads us to more questions such as how differently the enzymes affect the softwood and hardwood fibers, and whether the bonding properties of fines change. Enzyme treatment before and after mechanical treatment may cause quite different effects on the fibers. Normally, cellulase treatment before refining reduces refining time, while treatment after refining increases drainage.

Mechanical treatment on fibers for increasing fiber flexibility, fibrillation, and fiber straightening are usually accomplished by disk refiners in the mills and by PFI and valley beater in the labs. Another way of mechanical treatment on fibers could be simply hitting the fibers with steel rod, and we called it impact refining in this paper. This can not be an instant industrial practice, but need to be investigated for comparison. Impact refining is an old way of preparing bast fibers for making Korean traditional handmade paper, which is called as Hanji.

Fiber property itself is a controlling factor for paper properties. Fiber length and its distribution, wall thickness, chemical composition, and swelling ability are just a few names of paper property influencing factors. Softwood and hardwood fibers may be affected differently by enzymes and by mechanical treatment. Softwood and hardwood fines may have different bonding properties, and when the fines go through enzyme treatment, their behavior in fiber bonding may be changed further.

EXPERIMENT

In the study, cellulase-rich enzyme, Liftase A40, was used, which was provided by Ciba-Geigy Co. of Korean branch and whose CMC and xylanase activity were determined in our lab as 1245 $\pm$ 87 IU/ml (one unit is 1 μmol of reducing sugar/ one minute) and 545 $\pm$ 48 IU/ml, respectively. The enzyme we used was rich in cellulase and contained some xylanase. The fiber furnishes used in the experiment were hardwood bleached kraft pulp and softwood bleached kraft pulp. The hardwood was from Georgia-Pacific Co. in U.S.A. and was a mixture of maple, birch, and beech (Brightness ISO 90). The softwood was from the West Coast of U.S.A. and Douglas fir was the main component (Brightness ISO 84.6). The fiber furnishes for enzyme treatment were treated with Liftase A40 of 0.2% in OD fiber basis and at $50^{o}C$ for 30 minutes. Mechanical treatment was done with Valley beater and impact refining. Four different furnishes were prepared, which were the control, the enzyme pretreatment before refining, the enzyme post-treatment after refining, and the impact refining, respectively. We controlled the freeness of the furnishes to three levels (300, 400, and 500ml). For the case of the enzyme post-treatment after refining, the freeness before enzyme treatment was controlled. The enzyme treated furnishes were refined by Valley beater. Parts of the furnishes were classified by 150 mesh screen into 'fine-free fiber,' and fines. Handsheets were made with fine-free fibers only, and with whole fibers.

FIBER ANALYSIS

Refining time was much reduced for the enzyme pretreated furnish to reach to target freeness in **Figure 1** as we expected. Fiber length changes after enzyme treatment and refining were shown in **Figure 2** for softwood and hardwood. In the figure, the mean fiber length (length weighted, Kajaani FS-100) of the furnish from Valley beating was very close to that of the enzyme post-treated furnish after Valley beating. The enzyme pretreated furnish has notably short mean fiber length, but the furnish from impact refining has the fiber length close to the unbeaten furnish at any freeness levels. We believe enzyme treatment weakened the cellulose chains, and later by any mechanical action such as refining, fibers were cut into pieces. Impact refining did not changed fiber length significantly even at low freeness level (300 CSF). So, the freeness drop in impact refining is only due to the internal fibrillation inside the fibers.

Figure 3 shows the electron micrographes of softwood fibers at 300 ml CSF, where dramatic changes of fiber shapes were. Almost no fractures in the fibers were seen in impact refining, but only flat ribbon shapes were seen. Catastrophic disaster on fibers were shown in the furnish of the enzyme pretreated furnish. For the enzyme post-treated furnish, the surfaces of the fibers were cleaner than those refined by Valley beater, but we remember that no considerable fiber length differences were seen between the enzyme post-treated furnish and the Valley beater refined one in Fig. 2. Hardwood fibers gave less characteristic view than softwood fibers, but still gave the similar trends.

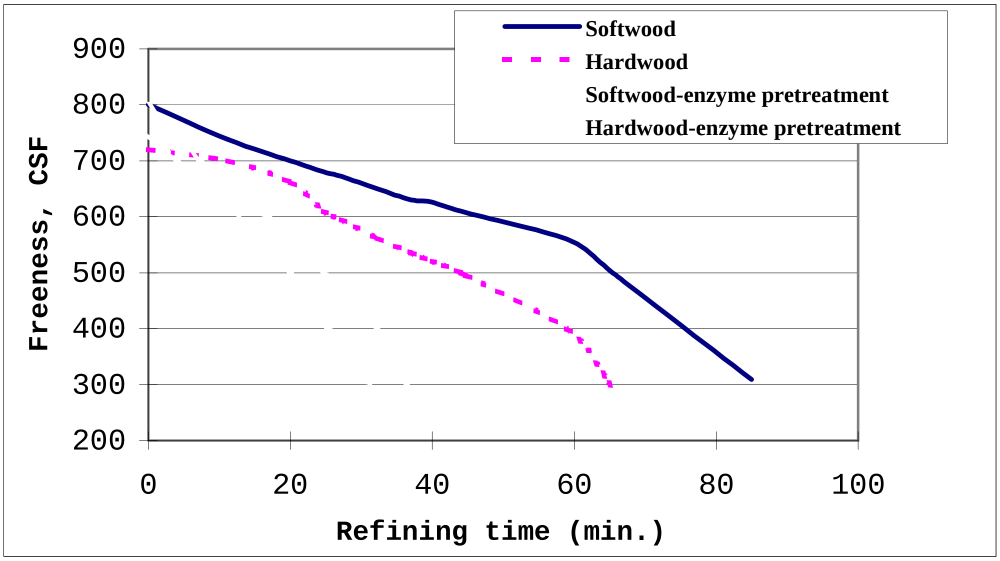

Figure 1. Effect of enzyme pretreatment on the refining time.

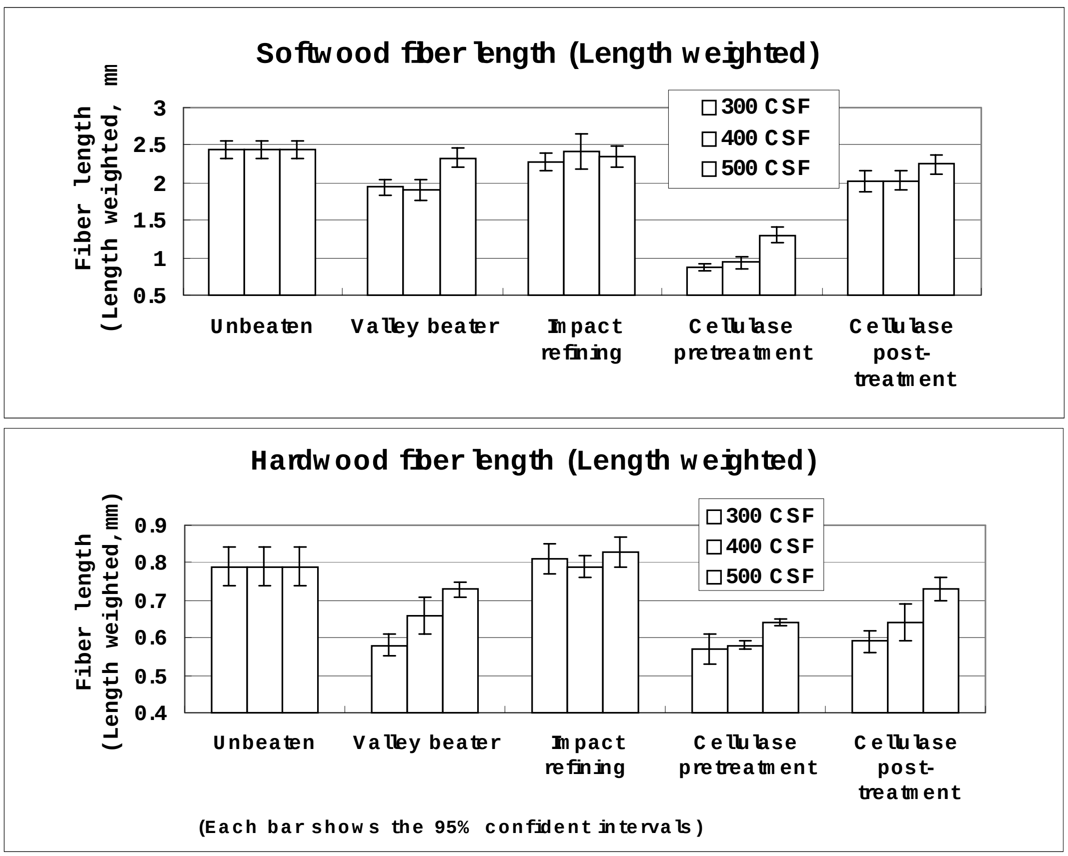

Figure 2. Fiber length of each fiber furnish after enzyme and mechanical treatment.

(A) Valley beating.

(B) Enzyme post-treatment after refining.

(C) Impact refining.

(D) Enzyme pretreatment before refining.

Figure 3. Electron micrographes of softwood pulp fibers treated by enzyme and refining (300 CSF).

The amount of fines that passed 150-mesh screen was shown in **Figure 4**. Impact refining generated the lowest amount of fines. Softwood showed strong effect of enzyme pretreatment by generating more fines while hardwood showed little differences between the furnishes with the enzyme pretreatment and Valley beater refining at low freeness levels (300 and 400 CSF). The enzyme post-treatment furnish gave almost the same amount of fines as the Valley beater refined furnish at all times. The enzyme post-treatment did not removed significant amount of fine as shown in the figure, but may have removed molecular level microfibrils that affect the furnish drainage greatly. Furnish drainage was measured by taking water draining time on the 200 mesh screen for 60g/m^2 furnish (TAPPI 221 om-88 method) with fines in **Figure 5** and without fines in **Figure 6**, respectively. In Fig. 5, enzyme post-treatment furnish shows the shortest drainage time than others especially at low freeness level (300 CSF), and the furnishes with large amount fines showed longer drainage time. In Fig. 6 where the furnish without fines were shown, drainage time differences became smaller or statistically became almost discernable.

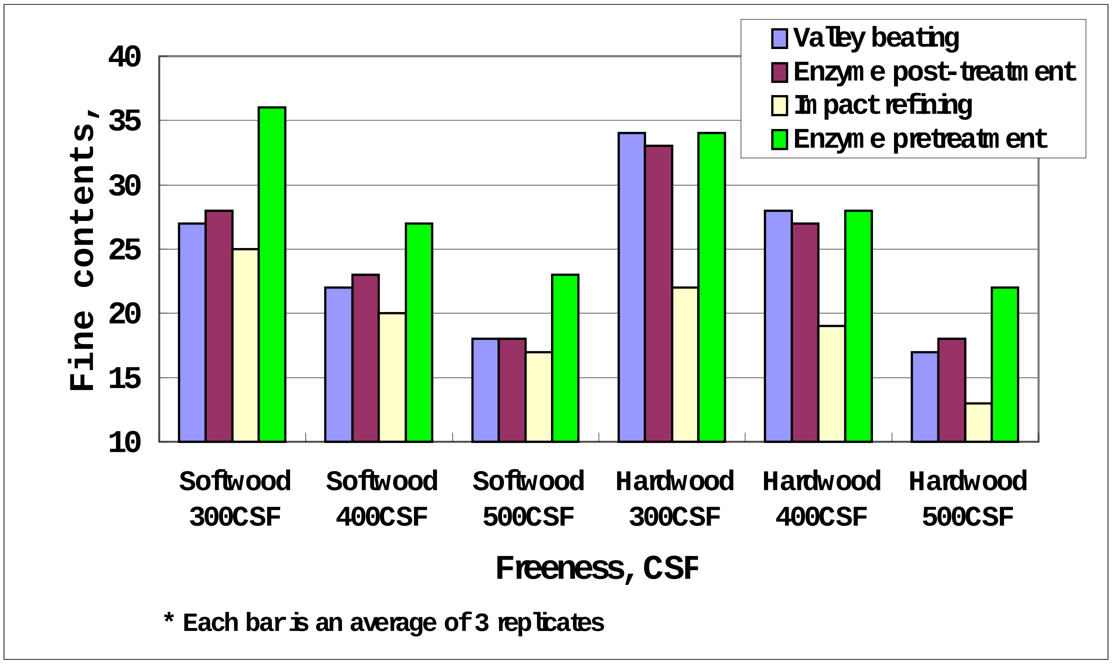

Figure 4. Fine contents in the softwood and hardwood furnishes.

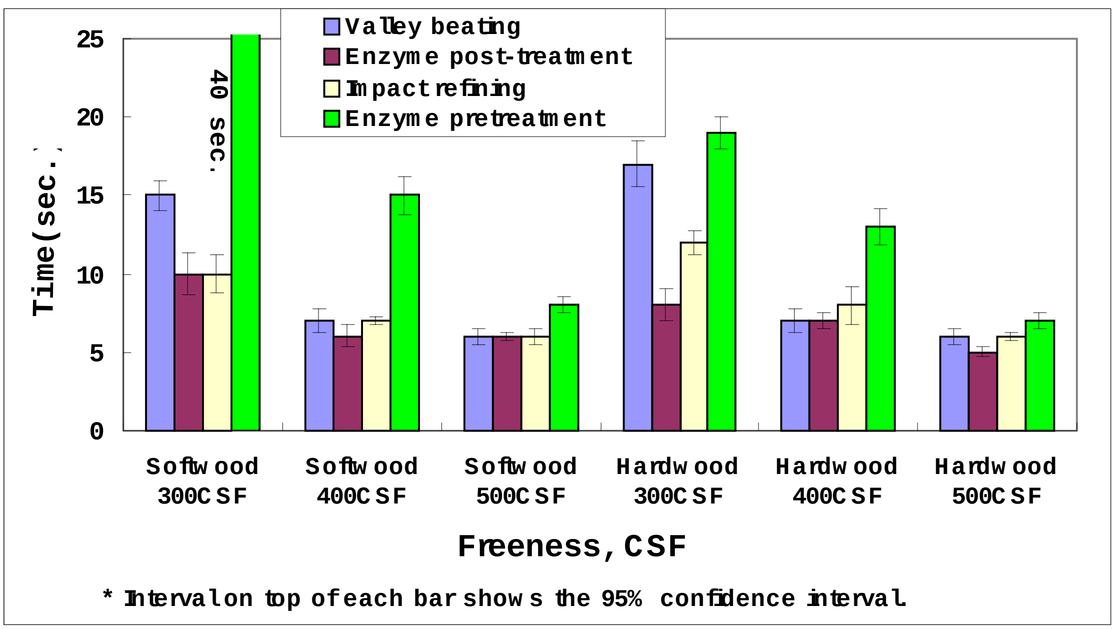

Figure 5. Drainage time of the whole furnishes with fines.

Water retention values (WRVs) gave somewhat different patterns from drainage time as shown in **Figures 7 and 8.** The furnishes with fines showed some differences in WRVs between treatments at the same freeness, but without fines, the enzyme pretreatment furnish and the impact refining furnish gave notably higher WRVs than the others. We believe this is because the fine removal treatment did not affect much the WRV of the impact refining furnish and the enzyme pretreated furnish still had large amount of short fibers even after its passing the 150 mesh screen. The figures also show that the enzyme post-treatment and the valley beating furnish have the similar WRVs all the times. We remember in Fig. 5 that the drainage time was shorter for the enzyme post-treatment furnish.

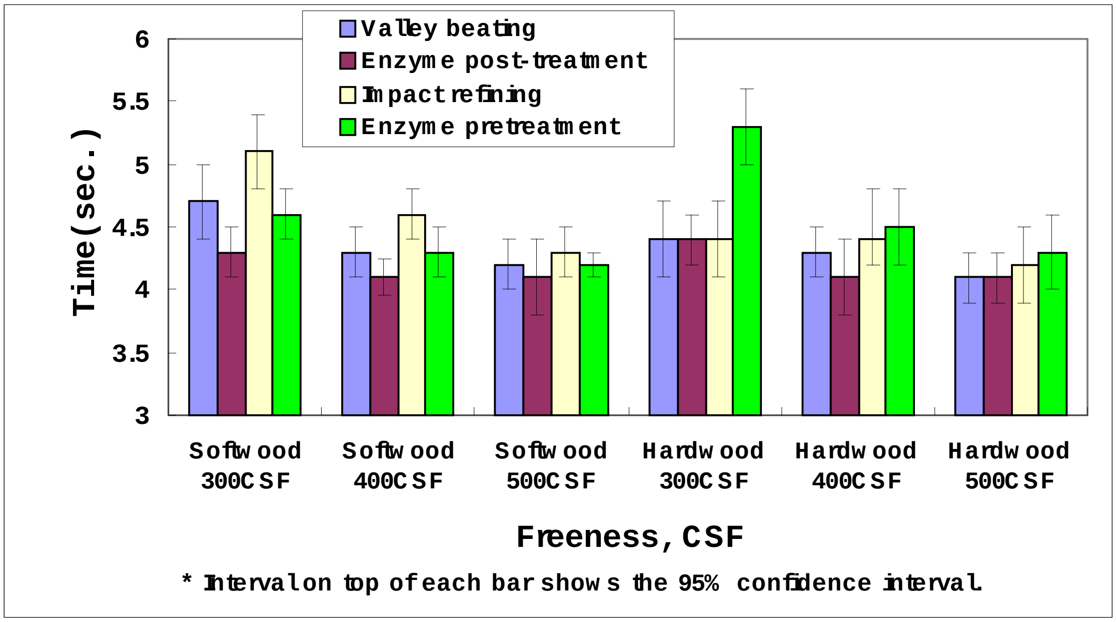

Figure 6. Drainage time of the classified furnishes without fines.

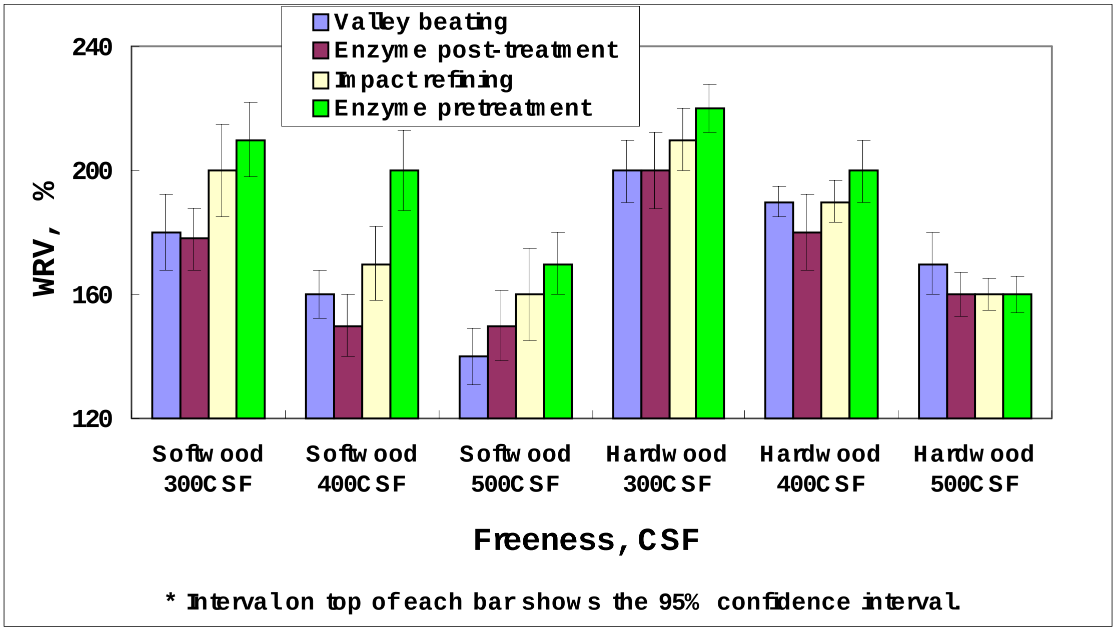

Figure 7. Water retention values of the whole furnishes with fines.

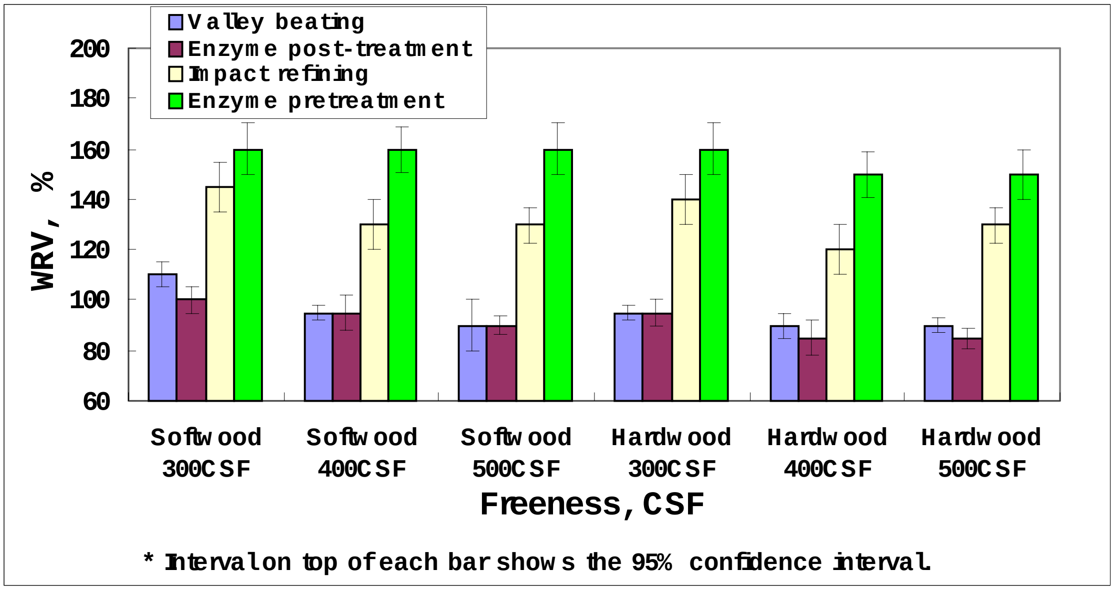

Figure 8. Water retention values of the classified furnishes without fines.

MECHANICAL PROPERTIES

After making handsheets from each treatment, strength properties were measured. The zero span tensile strength of the handsheet usually indicates the fiber strength. Both of the enzyme treated furnishes lowered zero span strength in **Figure 9** except enzyme post-treatment on softwood furnish. In hardwood, it seems that the enzyme post-treatment affected cellulose degradation more and its zero span strength was significantly lowered. This strength pattern was almost duplicated in breaking length in **Figure 10**.

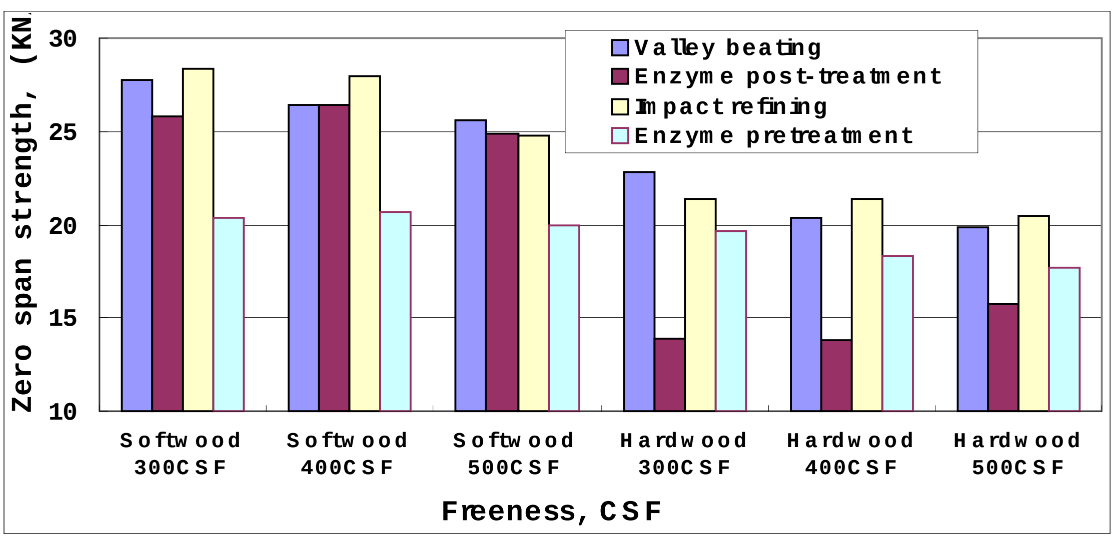

Figure 9. Zero span tensile strength of softwood and hardwood.

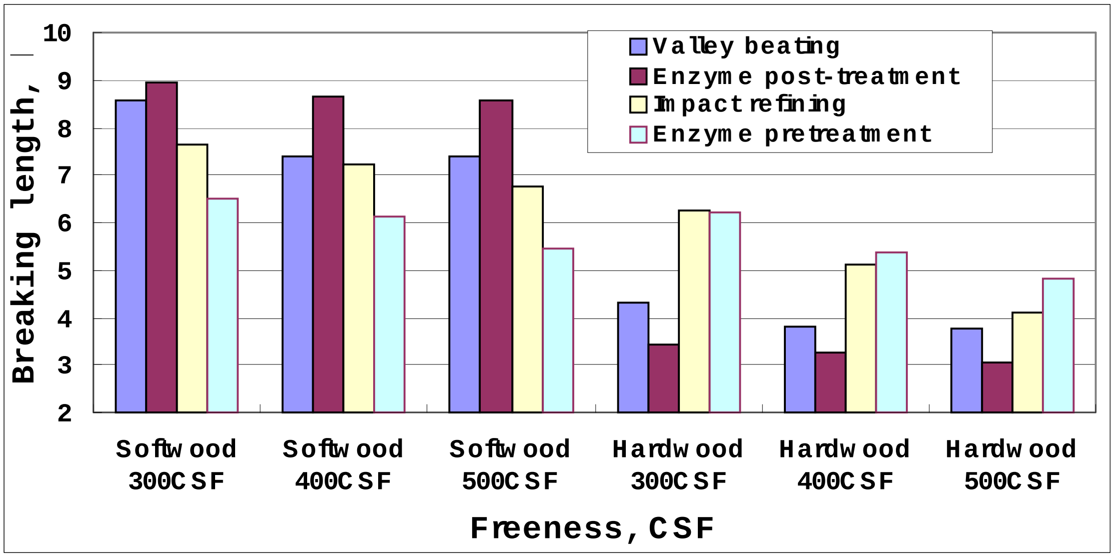

Figure 10. Breaking length of softwood and hardwood.

Fine effects on breaking length were investigated. The fine-free fiber fraction in the whole furnish will be (1-fine fraction). If the fines in the whole furnish do not contribute to the interfiber bonding at all, the breaking length of the whole furnish handsheet will be (1 – fine fraction) of the breaking length of the handsheet made with fine-free fibers only. We divide the whole furnish breaking length to (1 – fine fraction) of the breaking length of the handsheet made with fine-free fibers only and denote it as F. If fines have absolutely no bonding ability, F will be close to 1.0, and will be greater than 1.0 if fines have bonding ability. We divide F by the fine fraction of the handsheet to normalize it, and call it as 'Fine Bonding Ability.' The results of the Fine Bonding Ability calculations for different handsheets were shown in **Figure 11**. In the figure, we found that hardwood fines play more important roles in developing breaking length than softwood, and the fines from Valley beating were most effective in increasing breaking length. Fines from enzyme pretreatment seemed to be least effective in developing breaking length in both hardwood and softwood.

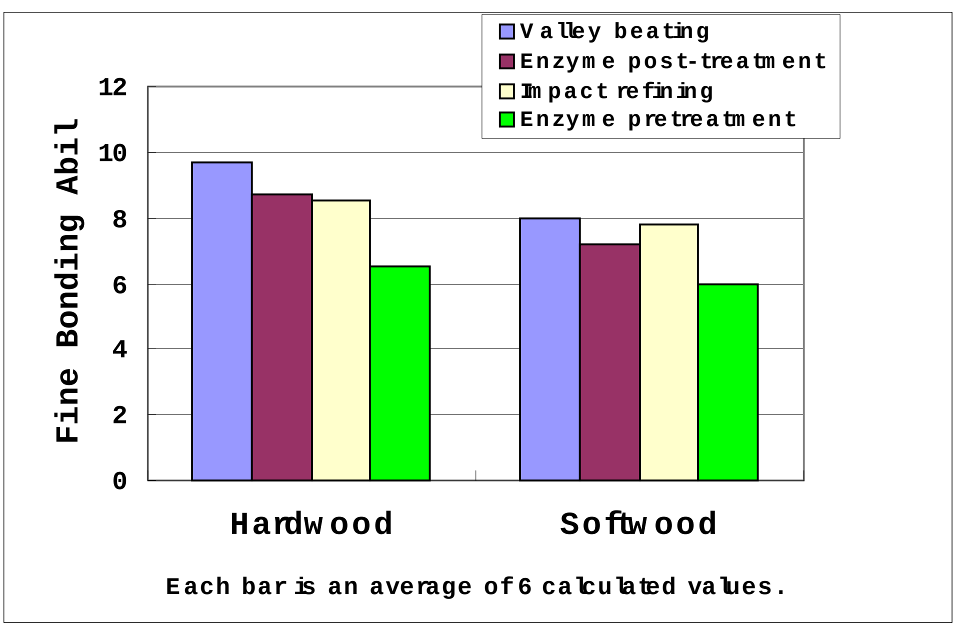

Figure 11. Fine bonding ability calculated from breaking length.

Conclusions

Combined treatment of the cellulase-rich enzyme (Liftase A40) and mechanical action on softwood and hardwood chemical pulp caused unique fiber and handsheet property changes. The enzyme treatment lowered the fiber strength at all times. The enzyme pretreatment shortened refining time by causing extensive fiber cutting, and the enzyme post-treatment removed 'molecular' level microfibrils to improve drainage without significant lowering of fiber length. Bonding ability of fines were lowered by the enzyme pretreatment. Impact refining kept fiber length from shortening effectively while freeness went down. Zero span tensile strength seemed to reflect how much the fibers were damaged by the cellulase-rich enzyme treatment.

These experimental results may be applied to various mill situations. For an example, if one mill has limitation in refining capacity, or needs to produce more fines for better internal bond, they may use cellulase-rich enzyme pretreatment as long as concerns were made enough about weakening fiber strength by the treatment.

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