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An Evaluation of Never-Dried Pulp at Multiple Freeness Levels

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An Evaluation of Never-dried Pulp at Multiple Freeness Levels.

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Printing and Paper Engineering Department
For Partial Completion of
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Abstract

Recycled paper is a viable and economical source of useful wood fiber for paper manufacture. Two of the largest contributors to today's paper waste stream are Mixed-Office Waste (Softwood Kraft Pulp) and Newsprint (Stone Groundwood Pulp). When paper is recycled the fibers are unavoidably, and irreversibly damaged. This damage is caused by Hornification (irreversible effect of re-drying fibers) and from the morphological changes on the fiber surface and structure from repeated re-slurring. The combination of these effects will affect the actual strength of the fiber, the bonding potential of the fiber and the freeness of the pulp (drainage rate equivalent). By tracking the fiber/bond strength, fiber length and freeness it was determined that Stone Groundwood and Softwood Kraft recycle similarly; although the Kraft pulp showed more significant changes in properties between recycles than the Groundwood. The Softwood Kraft consistently out-performed the Stone Groundwood as expected in physical testing, irrespective of freeness levels.

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Introduction

Today's future looks very different from the future of fifty years ago in the paper industry. Paper products used to represent 37.6% of land-filled materials, currently over half of that is now being recycled [1]. This is only after mammoth efforts have been undertaken to cut waste paper streams to what we consider "more acceptable". The demand for recovered fiber is growing faster than any other individual fiber type [2]. Lower costs and higher quality pulp fiber are attainable by properly utilizing recycled fibers [3]. By optimizing recycling techniques this once unwanted/under-utilized resource (paper fiber) can be maximized into a consistently profitable product.

Theoretical/Background Discussion

The objectives of this project were fourfold: track the freeness variations between recycles for each pulp, track sheet properties between recycles, Kajanni analysis of slurries and white water to determine that recycle technique was indeed "gentle", and the utilization of an up-right cement mixer as a high-consistency kneader as to not alter fiber surface characteristics (morphology) and fiber length (fines generation).

Many studies on paper recycling have shown that it is the change in fiber strength and fiber bonding potentials that account for the reduction of the sheet properties. However, many of these studies are not comparable. Some studies examined pulps at three freeness levels; but for only one recycle [4]. Certain studies tested several pulps and at a single constant freeness level and recycled fines [5]. Other studies allowed freeness to "float" but only evaluated one pulp type [6]. Even other studies evaluated blends of recycled fibers [7]. Being that the two major paper grades that get recycled are Mixed Office Waste (Softwood Kraft) and Newsprint (Stone Groundwood) it is only logical to compare the two, and determine similarities and differences over repeated recycles.

Attempting to isolate the effects of hornification, high consistency recycling techniques were utilized. This was to reduce fiber modification and alteration inherent in re-dispersion operations. High consistency recycling techniques have shown beneficial improvements in strength in recycling by reducing fiber damage [8]. The fiber-on-fiber shear re-disperses the fibers, allowing no fiber cutting or severe fiber surface morphology changes to occur. Fines therefore, should not be generated. Samples were evaluated via Kajanni fiber length analysis at every stage, pulp and white water, to determine if this "gentle recycle" method is acceptable. Fines were not recycled in the paper making process because they significantly effect sheet properties in closed water systems, which would not only complicate the experiment, but possibly mask results and mislead conclusions about hornification and freeness values.

Hornification is the reduction in fiber bonding and increased freeness from irreversible fiber hardening and loss of flexibility due to drying. The effects of hornification are most noticeable during the initial recycles of a pulp [9]. The sheet properties of recycled mechanical pulp do not change in the same manner as the properties of a chemical pulp [10]. Due to the differences in the two pulps being compared the Softwood Kraft pulp will have a higher fiber strength, while the Groundwood pulp should gave a larger bond area. The relative bonded area (RBA) of recycled fibers is lower than that of virgin fibers and continues to degrade over subsequent recycles. The bond strength is also lower for recycled fiber [11]. During successive recycles the paper properties tend to level out after approximately four recycles [8]. Sheet strength is also influenced by lignin content; and a certain lignin content improves strength [12]. An excess of lignin reduces effective bonding and increases fiber stiffness [13]. In this experiment the lignin content of the Groundwood pulp will not be determined or altered in any way. The Softwood Kraft pulp should have negligible lignin content due to its processing.

Bond strength and fiber strength in various degrees will determine the strength of the pulp and subsequent sheet. Failure will be achieved by either fiber failure or bond failure [16]. Fiber failure is generally a function of refining, bonding potential and fiber length [15]. Fiber strength was measured by Zero-Span Tensile [11]. Optical sheet properties were used to predict sheet strength, by relating light transmission to relative bond area, by applying the Kabulka-Monk theory [14]. Bond Strength was determined evaluating by Tear strength and Tensile strength.

While it is expected that due to the basic nature of the pulps, the Softwood Kraft pulp will out-perform the Groundwood pulp; but it is the purpose to evaluate *how* the pulps perform against each other considering the freeness variations and what nuances, if any, are revealed as the recycling progresses.

Experimental

Kraft and Groundwood pulps differ mainly with respect to how they are processed. The Kraft process utilizes chemicals to dissolve & remove lignin, yielding stronger fibers with a mostly unmodified surface morphology. Groundwood is produced by forcing logs against a grindstone which produces a fiber that is "shredded", having many fibrils allowing for increased bonding area but decreased fiber strength. I undertook all responsibility for the Groundwood pulp Noble and Wood hand-sheets and my partner worked with the Kraft pulp. Due to logistical difficulties my partner did all of the physical testing on both sets of hand-sheets. Data was unfortunately not collected for the freeness of the Kraft pulp or for the Kraft white water Kajanni analysis.

During our experiment fines were not recycled throughout the process, nor did we attempt to simulate specific industrial recycling process/procedure. Each parameter that was evaluated was specifically chosen to examine sheet strength. Sheet strength is characterized by average bond strength/bond area and fiber strength. Fines were examined to simply isolate the fact that they were not being significantly generated between and during recycles.

Observing the trend that after each recycle the effects of hornification become less significant, the initial recycle or Zeroth Recycle (initial drying) is a critical data point. Every time a fiber is dried, irreversible damage it done to the fiber. It becomes stiffer, and less flexible reducing the amount of potential bonding that the fiber had been able to attain in the previous recycle. Many paper grades are manufactured using dry lap pulp. Therefore before the pulp is made into a marketable product the fiber has already suffered the effects of hornification. Each pulp was procured from a supplier as never dried material. The Kraft pulp was shipped as a slurry and the Groundwood was shipped as pressed-lap pulp, but the moisture content was kept above 45% thus qualifying it as a never dried pulp.

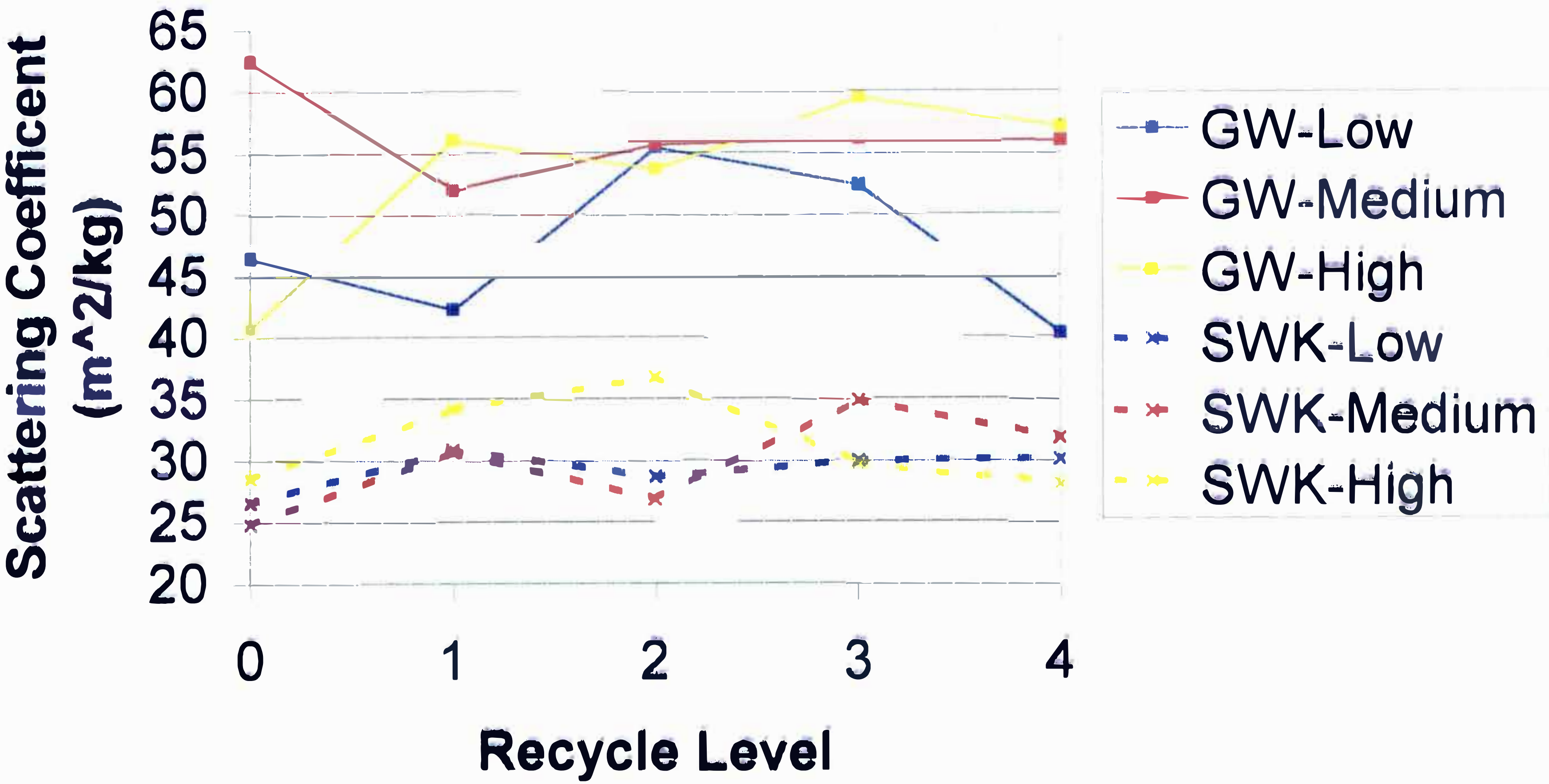
For each recycle, Noble and Wood handsheets were produced utilizing all of the pulp. The ten best sheets, based on target weight and formation, were removed for testing. The remaining sheets were soaked in de-ionized water for 24 hours. These saturated sheets were then ground in between the operators hands to reduce large flocs and finally run through a valley beater (with no blade load) for less than three minutes. This utilizes the shear force of the slurry to separate the fibers. The freeness was then recorded and the next batch of hand-sheets were produced. Samples of each pulp (and subsequent white water) were taken for Kajanni analysis. Optic #2 was used to be sensitive to long fibers of the pulp and the fines in the white water. Handsheet production and testing were randomized to reduce error due to improved technique. Standard deviations were calculated to substantiate that the data was accurate to true values.

By tracking the freeness levels we can determine the approximate drainage rate changes that the slurry undergoes naturally during recycling. This is important because any change in drainage properties effects runnibility on a paper machine from drier requirements, retention, and formation. The initial medium freeness levels for each pulp were chosen to represent a target, “on machine” freeness. Softwood Kraft pulp freeness is substantially higher (403 CSF) than Groundwood pulp (90 CSF). The high freeness levels were targeted at 150% of the target or medium freeness levels for each pulp. Similarly, the low freeness levels were targeted at 50% below the target freeness levels for each pulp.

Results

The results of the physical testing are summarized conveniently in Figures One – Five. The individual data points for each recycle group along with their corresponding standard deviations are provided in Appendices Two – Four. All of the physical testing was done specifically to determine bond strength (tear and tensile) and fiber strength (zero-span tensile). These properties were tested strictly to evaluate fiber-bonding potential and relative bonded area in accordance with the Kubulka-Munk analysis [14]. Aside from this, it was irrelevant to this experiment if the optical properties may have fluctuated.

FIGURE ONE: SCATTERING COEFFICIENT



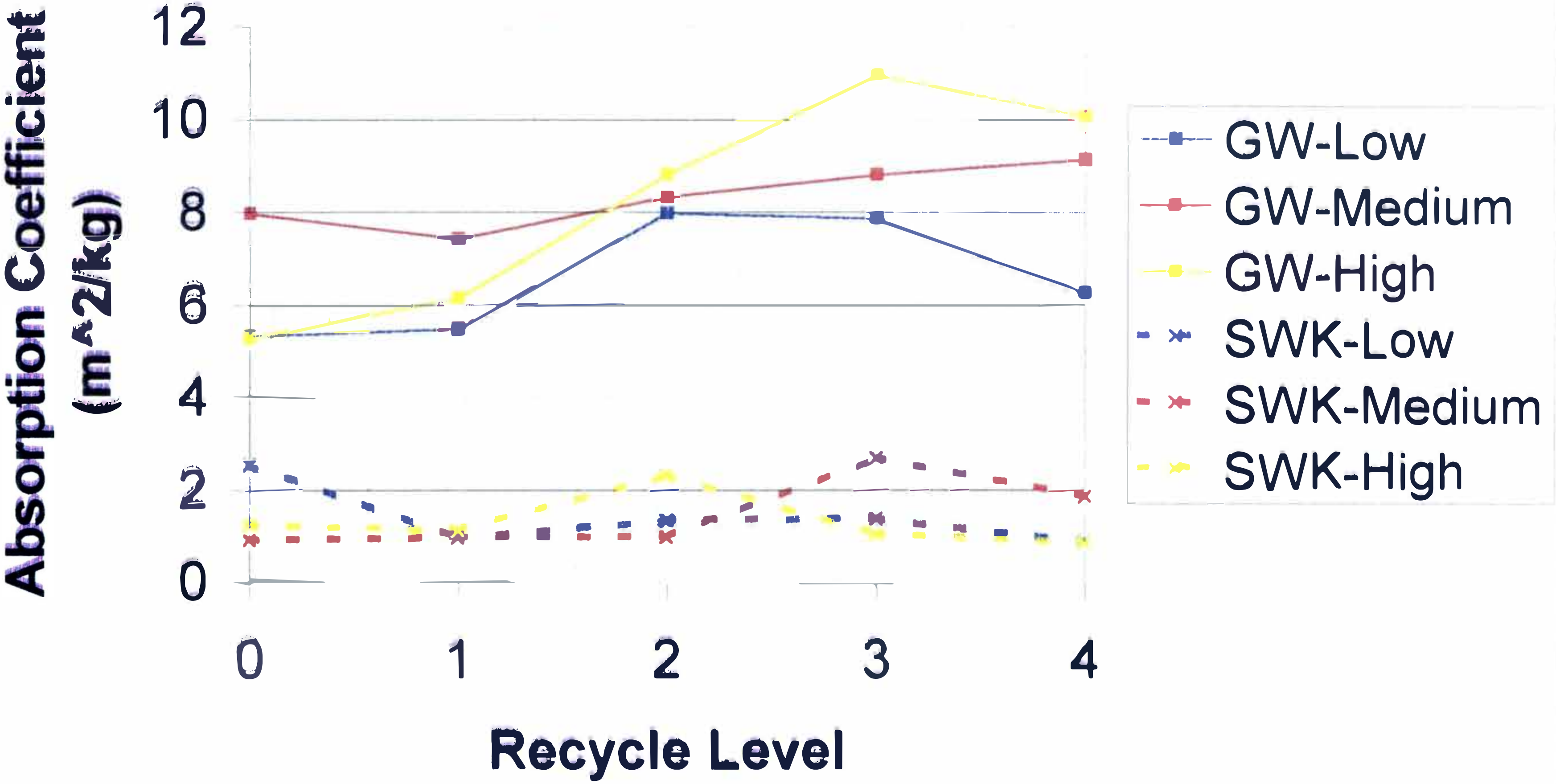


FIGURE TWO: ABSORPTION COEFFICIENT

FIGURE THREE: TENSILE INDEX

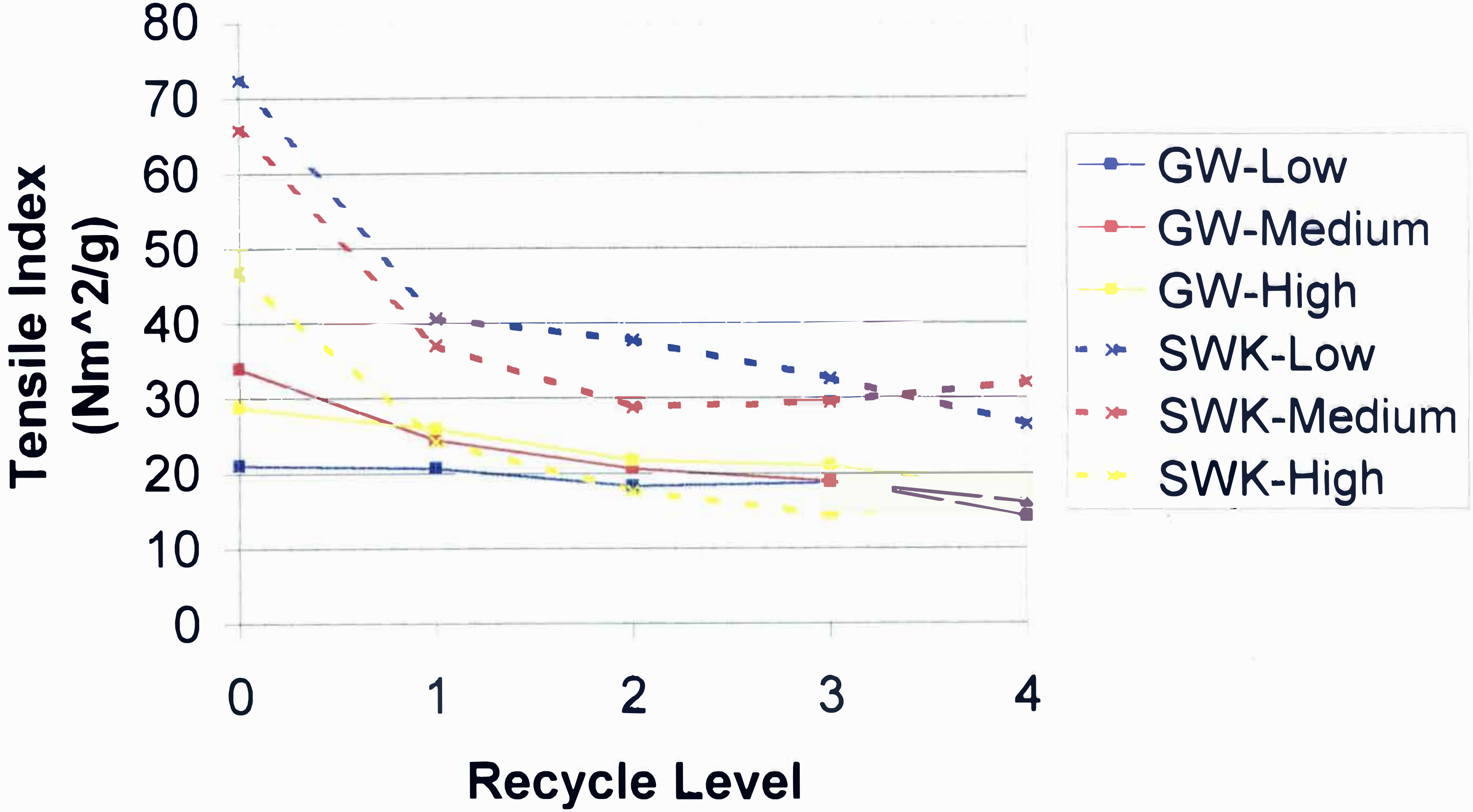


FIGURE FOUR: TEAR INDEX

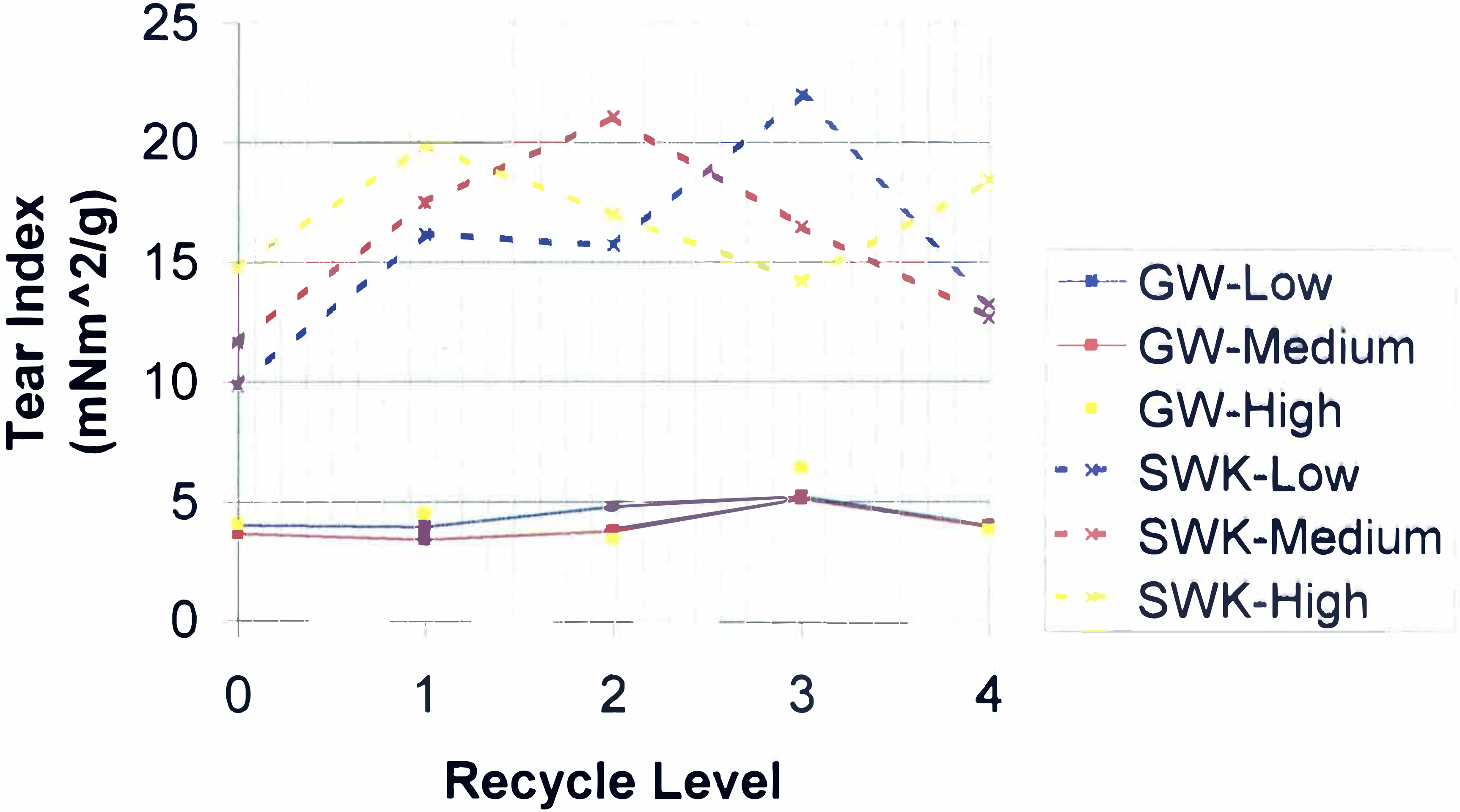
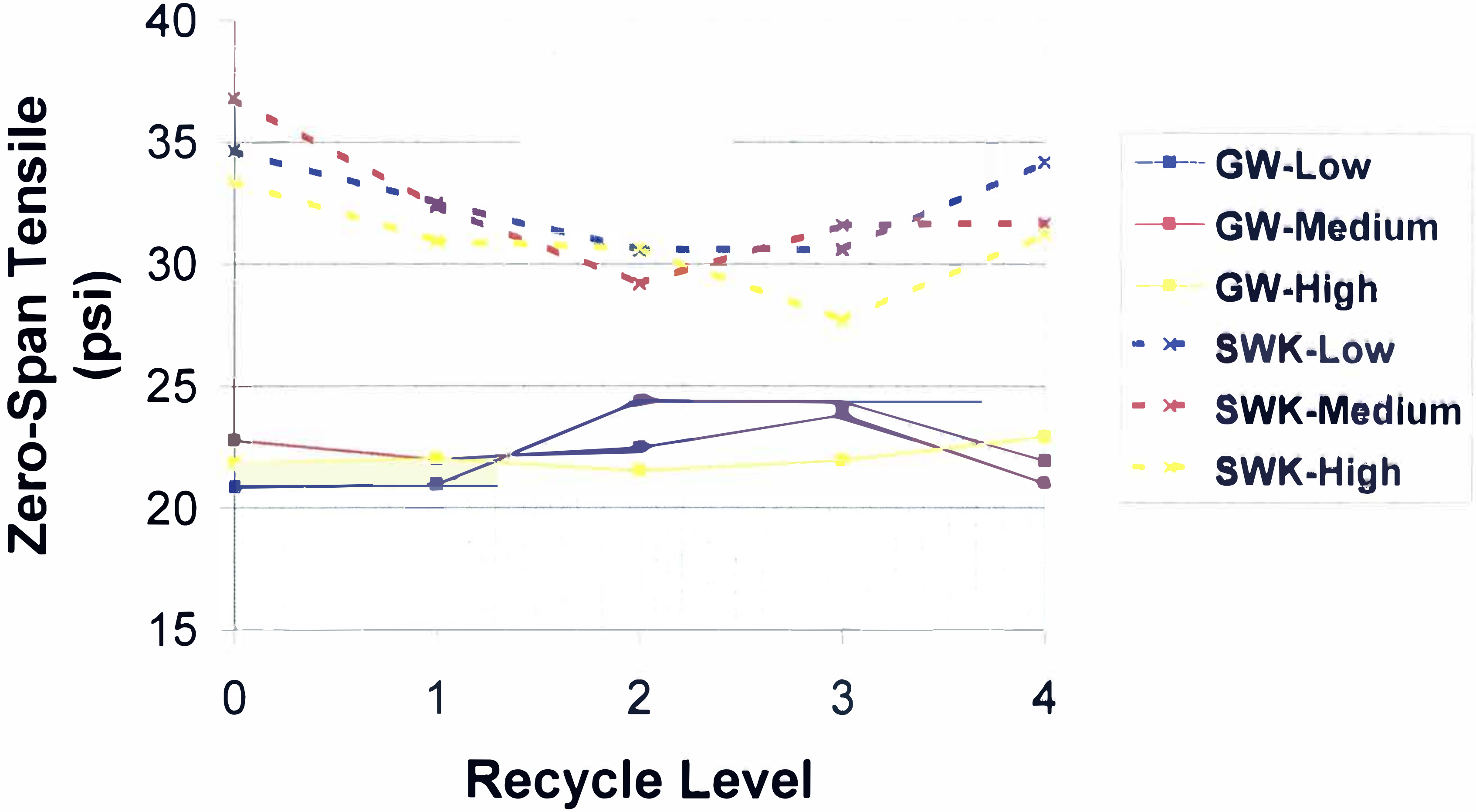


FIGURE FIVE: ZERO-SPAN TENSILE



Discussion of Results

Preliminary trial runs concluded that the use of a cement mixer for a high consistency kneader was ineffective. The baffle length and vessel size did not provide adequate fiber-on-fiber contact to re-disperse the fibers. In addition, the speed of the cement mixer was also insufficient to produce shear forces necessary to re-slurry the fibers.

Figures One and Two track scattering and absorption coefficients as calculated form opacity and brightness readings. Scattering coefficient if a measurement of free, non-bonded surfaces in the sheet. Thus from Figure One the Groundwood pulp has consistently more bonding area that the Softwood Kraft pulp.

Bond Strength is observed in Figures Three and Four. Tensile Index and Tear Index are indicative of bond strength. Tear Index and Tensile Index for the Groundwood recycles were significantly lower at every freeness level, which would indicate that with even more bonds, each individual bond is weaker that it's Softwood counterpart. The exception was the Tensile Index for the highly refined Softwood Kraft Pulp, due to the over-processing of the pulp.

Fiber Strength was determined by Zero-Span Tensile, Figure Five. As expected, the Softwood Kraft pulp consisted of fibers with higher inherent strength than the Groundwood pulp due to initial pulp processing.

From the Kajanni analysis we can determine that no significant fiber cutting/fine generation was incurred in re-slurring process. The Freeness values increased over subsequent recycles as anticipated.

Conclusions

1. A cement mixer cannot be used adequately as a high consistency kneader.
2. Due to incomplete data, a Freeness tracking comparison between the pulps was not possible; however the Stone Groundwood Freeness increased steadily over the entire experiment.
3. Softwood Kraft continuously outperformed Groundwood over four recycles irrespective of freeness levels due to their stronger fibers and bond strength. No nuances or unexpected subtleties were observed.
4. Kajanni Analysis of both pulps at every recycle level revealed no significant reduction in fiber length, allowing us to determine that our recycle technique was a "gentle recycle" technique.
5. The Kraft pulp's Fiber Length was not severely altered by beating, but was fiber strength/bonding properties diminished over the recycles, emphasizing that hornification effects are altering fiber characteristics.
6. The Groundwood pulp, while having more bonds than its counterpart, has weaker fibers and bond strength thus reducing the pulps overall performance.

Recommendations

This project began as a larger, clandestine experiment; it was reduced to a manageable workload with very specific goals and criteria. Repeating the same experiment while beating each recycle back to the initial "on machine" freeness level would yield worthwhile comparative data. Also the completion of Softwood Kraft White-Water Kajanni data would also re-enforce this project.

Acknowledgements

I would like to express my gratitude to Dr. David K. Peterson, of Western Michigan University's Printing and Paper Department for all of his patient and kind advice throughout this project. I would also like to thank Heath A. Smith, who also worked to make this more than just an experiment but a project, which we could both take ownership of.

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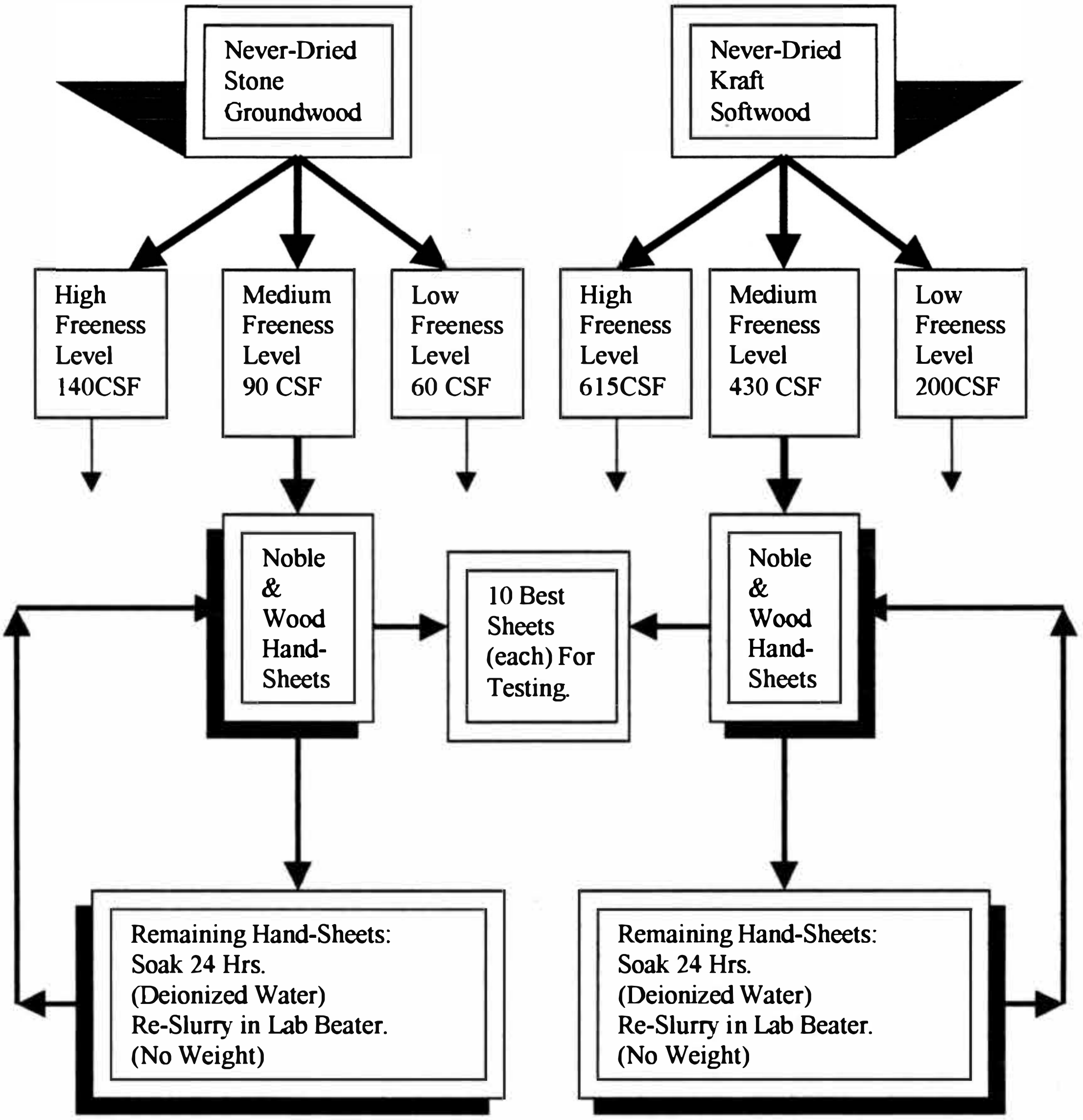
Appendices

Appendix One: Experimental Design



Appendix Two: Raw Data Stone Groundwood

Hand-sheet properties: Never-dried Stone Groundwood

	Basis Weight (g)	SD	Brightness (%)	SD	Opacity (%)	Scattering Coefficient (m^2/kg)	Absorption Coefficient (m^2/kg)	Tensile Index (Nm^2/g)	SD	Tear (mNm^2/g)	SD	Zero-Span Tensile psi	SD	Porosity (s/100ml)	SD
Low-1	2.53	0.07	69.18	0.63	50.53	46.11	5.2	20.8	3.4	3.96	1.1	20.8	1.4	8.58	1.9
Low-2	2.48	0.05	67.07	0.46	48.03	41.9	5.37	20.4	1.7	3.87	0.6	20.88	0.9	5.28	0.5
Low-3	2.51	0.07	66.06	0.63	46.4	55.06	7.88	18	3	4.69	0.9	24.28	1.4	5.06	0.2
Low-4	2.48	0.06	65.79	0.41	44.67	52.08	7.77	18.4	1.3	5.1	0.3	24.22	1.2	4.22	0.5
Low-5	2.46	0.02	62.55	0.55	43.04	39.87	6.16	15.7	2.1	3.9	0.3	21.8	0.6	4.52	0.8
Med-1	2.52	0.06	66.83	0.7	48.2	62.09	7.84	33.7	1.4	3.63	1	22.72	1.1	24.44	2.1
Med-2	2.47	0.07	66.36	0.9	46.57	51.72	7.31	24.2	2.4	3.35	0.3	21.92	0.8	9.22	1.9
Med-3	2.48	0.03	65.65	0.58	44.55	55.33	8.23	20.3	2.7	3.69	0.5	22.36	1.5	7.92	1
Med-4	2.52	0.04	65.39	0.58	43.17	55.77	8.71	18.6	1.7	5.02	0.6	23.68	2.3	6.2	0.5
Med-5	2.49	0.06	64.99	0.44	42.98	55.6	9.05	13.8	2.4	3.85	0.3	20.88	0.9	4.42	0.7
High-1	2.5	0.09	65.11	1.06	47.11	40.36	5.15	28.5	6.3	4.01	0.6	21.8	0.5	21.24	2.4
High-2	2.47	0.06	64.15	0.58	42.65	55.63	6.03	25.6	3	4.41	0.6	21.96	0.7	12.02	2.6
High-3	2.48	0.03	64.37	0.75	43.14	53.32	8.71	21.4	2.3	3.34	0.3	21.44	1.3	7.54	0.9
High-4	2.49	0.05	63.19	0.34	41.53	59.1	10.86	20.6	0.6	6.3	1.8	21.84	1.4	6.62	0.7
High-5	2.46	0.02	62.55	0.55	41.23	56.75	9.98	17	0.8	3.72	0	22.8	1	6.22	0.5

Appendix Three: Raw Data Kraft Softwood

Hand-sheet properties: Kraft Softwood

	Basis Weight (g)	SD	Brightness (%)	SD	Opacity (%)	Scattering Coefficient (m^2/kg)	Absorption Coefficient (m^2/kg)	Tensile Index (Nm^2/g)	SD	Tear (mNm^2/g)	SD	Zero-Span Tensile psi	SD	Porosity (s/100ml)	SD
Low-1	2.48	0.05	61.69	1.95	75.39	26.25	2.44	72.13	6.9	9.77	0.3	34.6	3.4	40.3	15
Low-2	2.51	0.08	71.18	1.93	74.37	30.57	0.87	40.37	3.4	16.1	1.7	32.44	1.8	5.02	0.2
Low-3	2.49	0.06	67.94	2.66	73.77	28.38	1.25	37.43	3.4	15.6	1.4	30.48	2.4	3.64	0.3
Low-4	2.46	0.04	62	2.56	75.02	29.67	1.3	32.23	1.9	21.9	1	30.48	2.6	2.74	0.3
Low-5	2.55	0.03	67.91	1.03	73.49	29.76	0.81	26.08	1.3	13.1	0.9	34.04	2.5	0.98	0.1
Med-1	2.52	0.06	66.72	1.11	68.61	24.52	0.81	65.5	6.5	11.6	0.3	36.78	1	7.3	0.9
Med-2	2.55	0.07	70.49	3.18	74.27	30.4	0.89	36.79	2.7	17.4	3.5	32.28	0.7	2.06	0.3
Med-3	2.5	0.08	68.72	1.94	71	26.62	0.89	28.42	3.2	21	2.1	29.08	2.7	1.4	0.3
Med-4	2.5	0.05	62.1	5.45	82.34	34.63	2.61	29.06	2.9	16.4	2	31.48	1.2	1.1	0.1
Med-5	2.55	0.03	64.95	1.61	77.98	31.56	1.78	31.74	1.1	12.55	1.4	31.52	1.1	2.2	0.4
High-1	2.52	0.06	70.02	1.52	73.27	28.23	1.13	46.73	5.7	14.7	0.7	33.36	1.9	1.8	0.2
High-2	2.52	0.07	73.66	1.8	77.26	33.83	1.03	23.94	2.4	19.8	2.5	30.88	2.9	0.54	0.2
High-3	2.51	0.06	67.05	1.52	82.48	36.5	2.23	17.36	2.9	16.9	2.1	30.56	1.5	No Data	
High-4	2.46	0.06	68.95	2.69	73.66	29.38	0.95	14.04	4.1	14.1	0.4	27.6	2.5	No Data	
High-5	2.51	0.06	69.6	1.24	71.75	27.77	0.8	16.61	1.9	18.3	0.5	31.12	2.5	No Data	

Appendix Four: Raw Data

Kajanni and Freeness Data

Freeness Data (CSF): Stone Groundwood

Refining Level	Zeroth Recycle	Recycle #1	Recycle #2	Recycle #3	Recycle #4
High	140	190	250	320	330
Medium	90	130	230	240	320
Low	60	125	180	270	235

Kraft Softwood Pulp:
Arithmetic Kajanni Fiber Length Analysis :

Refining Level	Zeroth Recycle	Recycle #1	Recycle #2	Recycle #3	Recycle #4
High	No Data	0.51	0.53	0.62	No Data
Medium	No Data	0.81	0.62	0.64	0.47
Low	No Data	0.61	0.61	0.65	0.62

Kraft Softwood Pulp:
Weighted Kajanni Fiber Length Analysis:

Refining Level	Zeroth Recycle	Recycle #1	Recycle #2	Recycle #3	Recycle #4
High	No Data	1.18	1.1	1.28	No Data
Medium	No Data	1.59	1.32	1.32	0.99
Low	No Data	1.41	1.31	1.29	1.23

Stone Groundwood Pulp:
Arithmetic Kajanni Fiber Length Analysis :

Refining Level	Zeroth Recycle	Recycle #1	Recycle #2	Recycle #3	Recycle #4
High	0.32	0.32	0.33	0.32	0.32
Medium	0.31	0.32	0.34	0.34	0.33
Low	0.33	0.31	0.35	0.35	0.35

Stone Groundwood Pulp:
Weighted Kajanni Fiber Length Analysis :

Refining Level	Zeroth Recycle	Recycle #1	Recycle #2	Recycle #3	Recycle #4
High	0.6	0.63	0.65	0.65	0.62
Medium	0.61	0.63	0.68	0.64	0.63
Low	0.68	0.64	0.7	0.76	0.73

Stone Groundwood White Water:
Arithmetic Kajanni Fiber Length Analysis :

Refining Level	Zeroth Recycle	Recycle #1	Recycle #2	Recycle #3	Recycle #4
High	0.17	0.16	0.18	0.22	0.22
Medium	0.24	0.16	0.2	0.2	0.2
Low	0.26	0.19	0.17	0.19	0.22

Stone Groundwood White Water:
Weighted Kajanni Fiber Length Analysis :

Refining Level	Zeroth Recycle	Recycle #1	Recycle #2	Recycle #3	Recycle #4
High	0.39	0.32	0.51	0.49	0.48
Medium	0.58	0.37	0.43	0.62	0.57
Low	0.59	0.45	0.39	0.48	0.49