

Adding Value to Recovered Paper using Fibre Fractionation

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ABSTRACT

In excess of one million tonnes of recovered paper is collected annually in South Africa. This is 62% of the available recoverable paper. Paper fibres deteriorate in strength during each recycling cycle.

Fractionation is the process of classifying pulp according to specific fibre properties, including fibre length, cell wall thickness (CWT) and degree of fibrillation. Using fractionation, a pulp of better quality and uniformity may be produced. This project involved the testing of two types of fractionating equipment viz., hydrocyclones and screens to fractionate two types of recycled fibre pulp viz; common mixed recovered paper (C+) and heavy letter one (HL 1). After fractionation, the refined long fibre fraction (LFF) or rejects was combined with the unrefined short fibre fraction (SFF) or accepts, to achieve a better quality pulp, than the unfractionated, unrefined feedstock.

The hydrocyclone was found to be the best method for fractionating both the C+ and HL 1 grades of recovered paper with respect to tensile strength.

1. INTRODUCTION

It is imperative that the South African paper industry recovers as much paper as possible. Recovered paper is a valuable resource and recycling paper into new paper products has a lower environmental footprint than using virgin fibre. In addition, by recycling paper, the amount of waste sent to landfill, is reduced. One ton of recycled paper can save up to three cubic metres of landfill space and subsequently reduce transport costs for local municipalities (PRASA, accessed on 19 June 2014). Recovered fibre is generally recycled more than once. After repeated recycling, fibres become less flexible and degrade due to a process called hornification resulting in reduced strength and bonding properties caused by the loss of the ability to swell when rewetted (Peel,1999). Methods such as fractionation can enhance the physical properties of recycled pulp.

2. BACKGROUND

Printing and writing grades of paper that are recovered locally for conversion to tissue are:

1. Heavy letter one (HL1) consisting of recovered white office paper like photocopy paper, either printed or unprinted.
2. Heavy letter two (HL2) consisting of pastel coloured printed or unprinted sheets, shavings and cuttings originating from printers or office records (PRASA, accessed on 19 June 2014).
3. Common mixed recovered paper (C+) consisting of the scraps that are left over after the sorting of HL1 and HL2.

The impacts of recycling on the paper properties are determined by:

1. Whether the raw material is comprised of mechanical or chemical pulp
2. The number of times the fibre has been recycled
3. The proportion of virgin fibre entering the system at each recycle phase (Peel, 1999)

The amount of virgin fibre in the recovered paper has a significant impact on the properties of the recycled paper product. Tensile strength decreases with each recycle of chemical pulp based paper (Gottsching, 1997). Tensile strength of tissue products is of primary importance.

Both HL1 and C+ are papers produced from bleached chemical pulps, which may contain a blend of virgin and recycled fibre. In addition, each grade of printing and writing paper consists of blends of hardwood and softwood fibres. Hardwood fibres are short and thin and softwood fibres are longer and larger in diameter. The strength properties of fibres can be improved by refining. However, the refining of shorter, weaker fibres

that have been recycled several times results in fibre degradation and lower strength properties. If the longer more resilient fibres could be separated out, before refining, refined and then recombined with the shorter, more heavily recycled fibres, a stronger pulp can be expected (Fig. 1). In addition, refining of a partial stream flow as opposed to the full stream flow will result in energy savings.

Fractionation is the process of classifying pulp according to properties such as fibre length, cell wall thickness (CWT) and degree of fibrillation. Fractionation splits the pulp into two fractions, namely the accepts or short fibre fraction (SFF) and the rejects or long fibre fraction (LFF). Fractionation in the paper industry is accomplished with the aid of pressure screens or hydrocyclones.

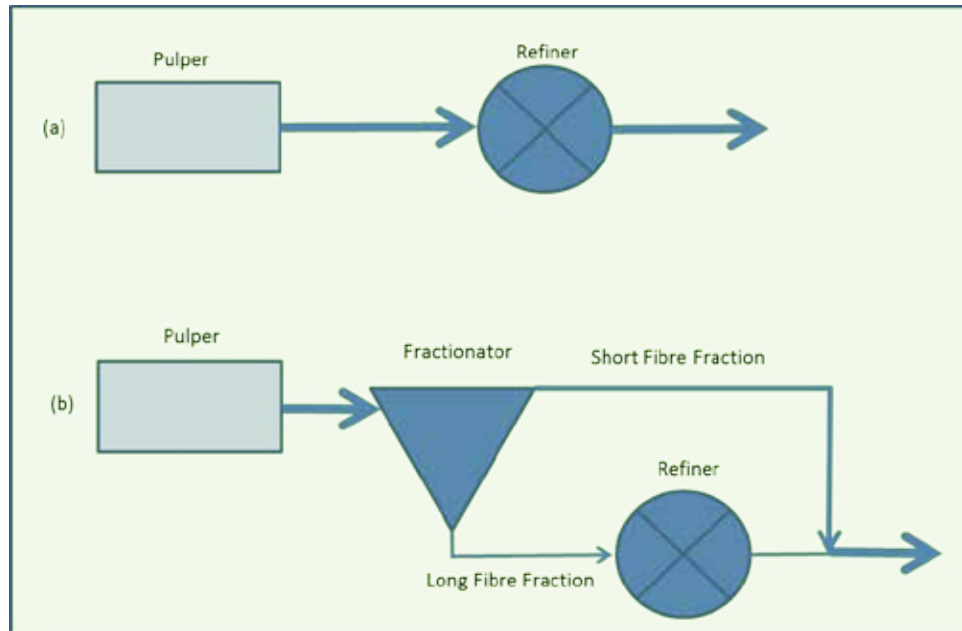


Figure 1: Refining of full pulp stream flow (a) vs. full partial pulp stream flow (b)

3. METHOD

3.1 Hydrocyclone

The laboratory hydrocyclone setup that was used for the fractionation studies is shown in Figure 2. The system was comprised of a Noss Hydrocyclone, a mixing tank, a positive displacement pump and a control unit.



Figure 2: Laboratory hydrocyclone setup.

The hydrocyclone flow rates and pressures were set in accordance with the study conducted by Bush and Johakimu (2010), which were 100-110 L/min and 2-2.3 bar respectively. No previous studies had been conducted on the hydrocyclone using raw materials used in this study, so the optimum parameters for

fractionation had to first be determined. Consistencies of 0.8%, 0.4% and 0.2% were used for each of the recycled fibre grades. Mass reject ratios of 0.2, 0.3 and 0.4 were used. There were no measurement meters on the hydrocyclone, thus the mass reject ratio was calculated by timing the amount of pulp that flowed into a bucket, from the base and apex of the hydrocyclone. The buckets were then weighed and the mass reject ratio calculated. Changing the consistency and mass reject ratio of the hydrocyclone satisfied the objective of changing operating parameters to find the best conditions for fractionation in a hydrocyclone.

3.2 Pressure Screen

An Andritz Fiedler trial unit with screen basket and rotors (pressure screen) was used for screen fractionation. The components of the pressure screen can be observed in Figures 3a and 3b.



Figure 3: The two elements of the pressure screen: a) screen unit with installed pipes and measurement equipment and b) pump unit

The pressure screen was operated in the tissue mill while the plant was running. Feed flow rates were between 200 – 300 L/min. Electrically controlled valves controlled the flows from the accepts and rejects outlets. Flow meters on the feed and accept lines displayed the volumetric flows on the DCS. The volumetric reject ratio was calculated from the feed and reject volumetric flow rates. Volumetric reject ratios of 0.3, 0.5 and 0.8 were used. Slotted screens of 0.2 mm and 0.25 mm were used. An Andritz Ro-Tec™ HC (high consistency) rotor was used for the screening trials.

In both cases viz., screening and hydrocyclone trials, the conditions which gave the highest fractionation indices were established and the pulp samples from those trials were then tested for tensile strength. The rejects were refined and recombined with the accepts to determine the effect on tensile strength of the combined stream.

3.3 Refining

The HL1 and C+ reject samples, from the hydrocyclone and pressure screen runs that gave the best fractionation efficiencies were refined in a PFI mill at various beating levels and then tested for tensile strength. In both cases, the refined rejects were recombined with the unrefined accepts in the ratio at which they were separated, and tensile strength values were determined.

3.4 Field Emission Gun Scanning Electron Microscope (FEG-SEM) and Cell Wall Thickness (CWT) analysis

An investigation into the cell wall thickness (CWT) of samples from one hydrocyclone trial was undertaken. This analysis was done at the Sappi Tech Centre, in Pretoria. Cell wall thickness was measured on the feed, accepts and rejects of C+ which was passed through the hydrocyclone at a consistency and reject ratio of 0.2% and 40% respectively. The analysis was only done on this one sample to investigate the effectiveness of the hydrocyclone in separating fibres based on their CWT.

A field emission gun scanning electron microscope evaluation (FEG – SEM) was also carried out on the same samples, to determine the morphological characteristics which may have impacted on pulp strength, such as fibrillation and cell wall delamination.

4. RESULTS

4.1 Heavy Letter One (HL1) and Common mixed recovered paper (C+) fractionation results

Fractionation indices were obtained for the two types of pulps using the hydrocyclone and screen. The reject ratio was varied in order to determine the best operating conditions for both. In addition, the consistency of the pulp was varied in the hydrocyclone trials and the screen slot dimensions were varied in the screening trials. It was not possible to vary the consistencies in the screening trials since this unit was run in the mill under normal mill operating conditions. The results for the hydrocyclone and screening trials are shown in Figures 4 and 5 as well as Table 1.

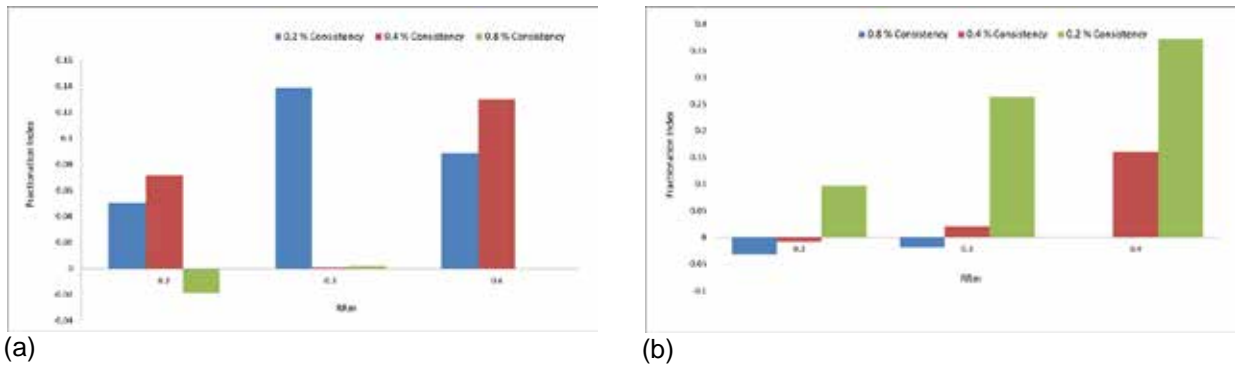


Figure 4: Fractionation indices for (a) HL1 and (b) C+ using the hydrocyclone, at various consistencies and mass reject ratios (RRm)

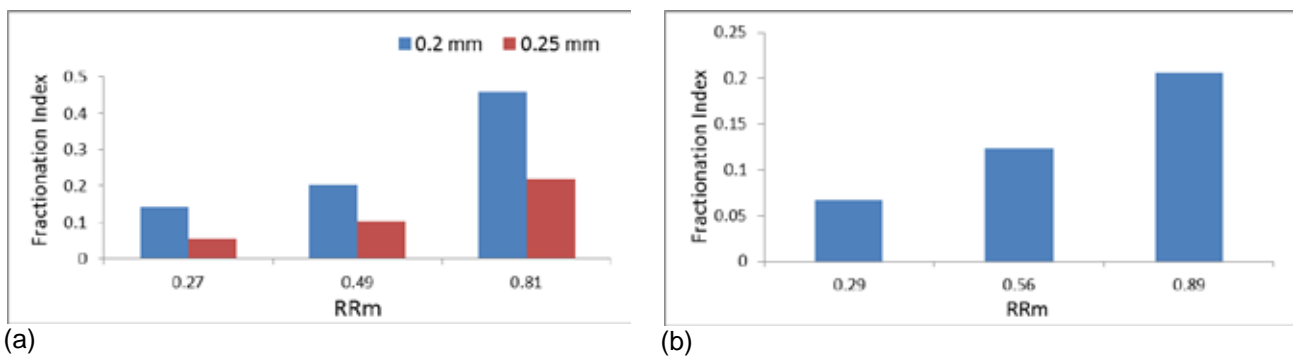


Figure 5: Fractionation indices of (a) HL1 and (b) C+ using the pressure screen at different slot sizes (HL1 only) and mass reject ratios (RRm)

Table 1: Operating parameters at which the highest fractionation index (ϕ) and strength properties with respect to the feed indices occurred for the hydrocyclone and pressure screen trials, and for each furnish.

Equipment	Furnish	Consistency (%)	RRm	Slot Size (mm)	Highest ϕ	Highest Strength Relative to the Feed Index
Hydrocyclone	HL1	0.2	0.3	N/A	Yes	No
		0.2	0.4	N/A	No	Yes
	C+	0.2	0.4	N/A	Yes	Yes
Pressure Screen	HL1	4	0.81	0.2	Yes	Erratic
	C+	4	0.89	0.2	Yes	No

Pulp samples from the trials were then used for the testing of the tensile strength properties. The tensile strength results are shown in Figures 6 and 7 for hydrocyclone and screening trials respectively.

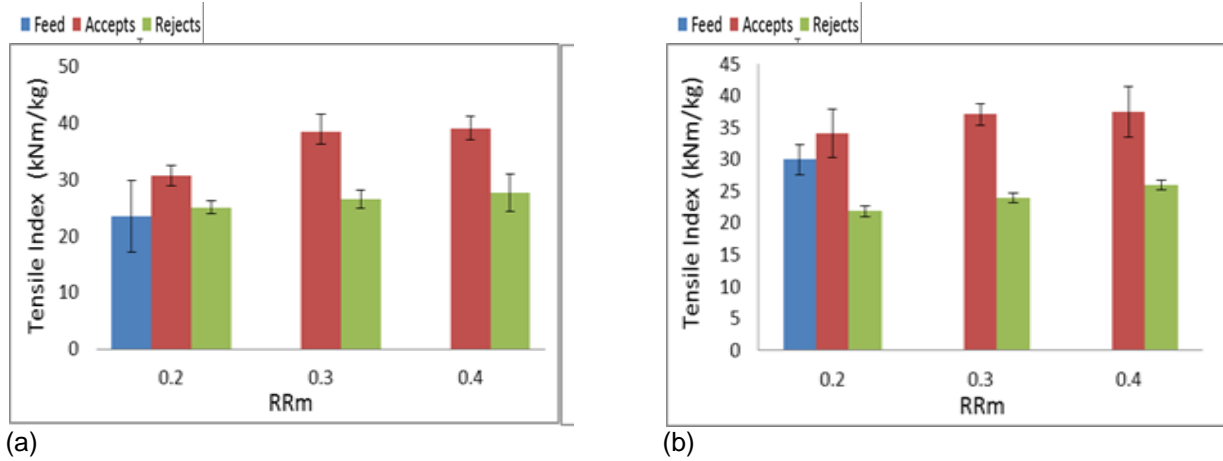


Figure 6: Tensile indices of (a) HL1 and (b) C+ at a consistency of 0.2%, and various mass reject ratios from the hydrocyclone tests.

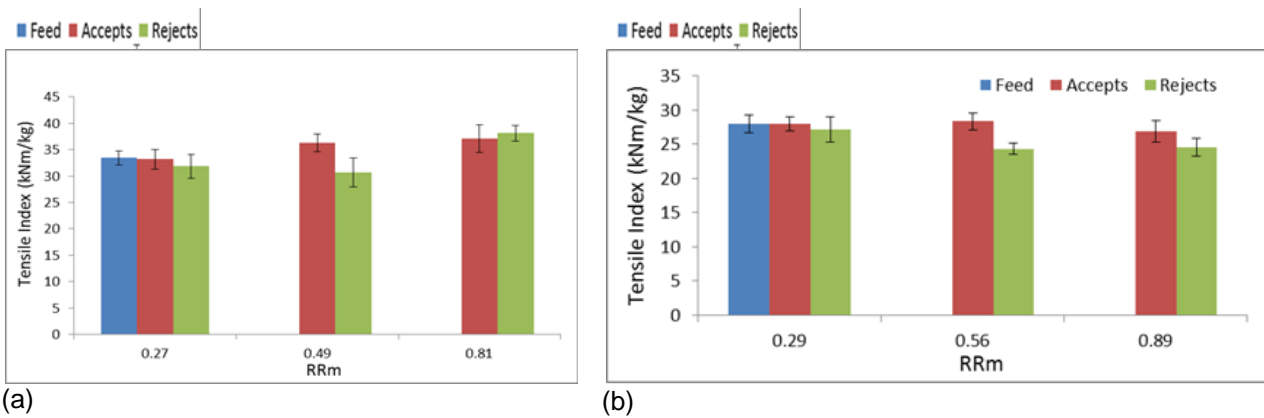


Figure 7: Tensile Indices of (a) HL1 and (b) C+ using slotted screens of 0.2mm and at different mass reject ratios.

4.3 Refining of rejects stream and recombination with the accepts stream

Figure 8 shows the tensile indices of HL1 for the hydrocyclone and pressure screen trials, with and without refining of the rejects stream, compared to virgin hardwood and virgin softwood pulps. The tensile strength of the recombined stream (RE) after combining the accepts (short fibre fraction) stream with the refined rejects (long fibre fraction) stream (refined at 5 000 revolutions) are also shown. The hydrocyclone rejects sample was taken from the hydrocyclone operated at a consistency of 0.2% and mass reject ratio of 0.4. The pressure screen rejects sample was taken from the pressure screen fitted with a slotted screen with 0.2mm slots and run at a mass reject ratio of 0.81 and consistency of about 4 %.

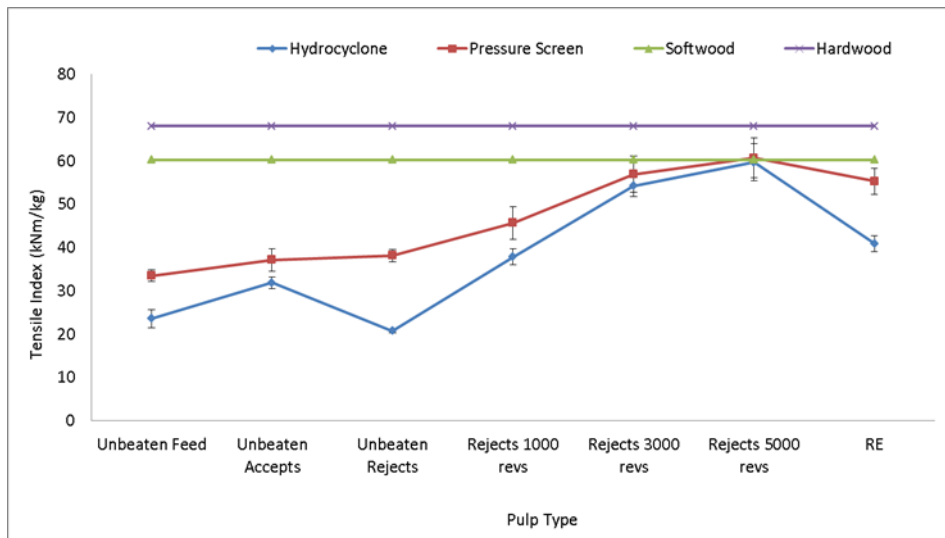


Figure 8: The tensile indices of HL1 for the hydrocyclone and pressure screen trials.

Figure 9 shows the tensile indices of C+ and HL1 for the hydrocyclone trials. The hydrocyclone rejects sample used was taken from the hydrocyclone run at a consistency of 0.2% and mass reject ratio of 0.4. The recombined tensile indices for each raw material are also shown along with the tensile indices of the virgin fibre.

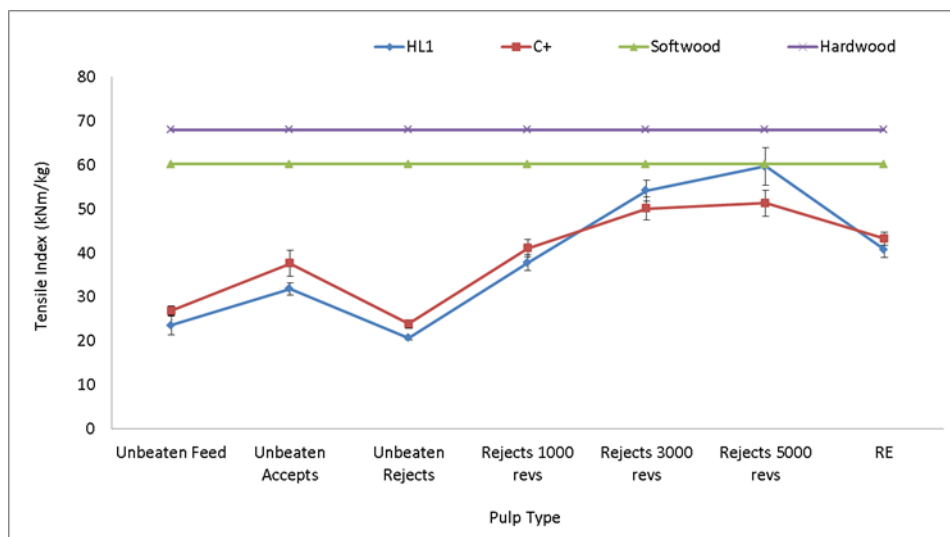


Figure 9: Tensile indices of C+ and HL1 for the hydrocyclone trials

4.4 Field Emission Gun Scanning Electron Microscope (FEG-SEM) and Cell Wall Thickness (CWT) analysis of common mixed recovered paper

Figure 10(a) and figure 10(b) are photomicrographs of the cross section of the accepts and rejects handsheets respectively, where a mass reject ratio of 0.4 was applied in the hydrocyclone, with a pulp consistency of 0,25%. A single handsheet was used for each sample, from which two small rectangular sections were cut and prepared for the Carl Zeiss field emission gun scanning electron microscope (FEG-SEM). The biggest observable difference between the fibre fractions appeared to be the packing of the fibres. The accepts fibres were packed more tightly together than the rejects. This was due to the higher collapsibility of the fibres in the accepts, which implies thinner, more damaged cell walls.

The accepts fibres also appeared to be more fibrillated than those of the rejects. This high degree of external fibrillation probably resulted in the accepts possessing the higher tensile strength compared to the rejects, before refining. Since tensile strength is mostly dependant on bonding between fibres, this fibrillation in the accepts probably resulted in more hydrogen bonds forming, thereby resulting in the high degree of inter-fibre bonding. This indicates that the hydrocyclone most likely fractionated more on the basis of the degree of fibre fibrillation/fibre treatment, rather than fibre length.

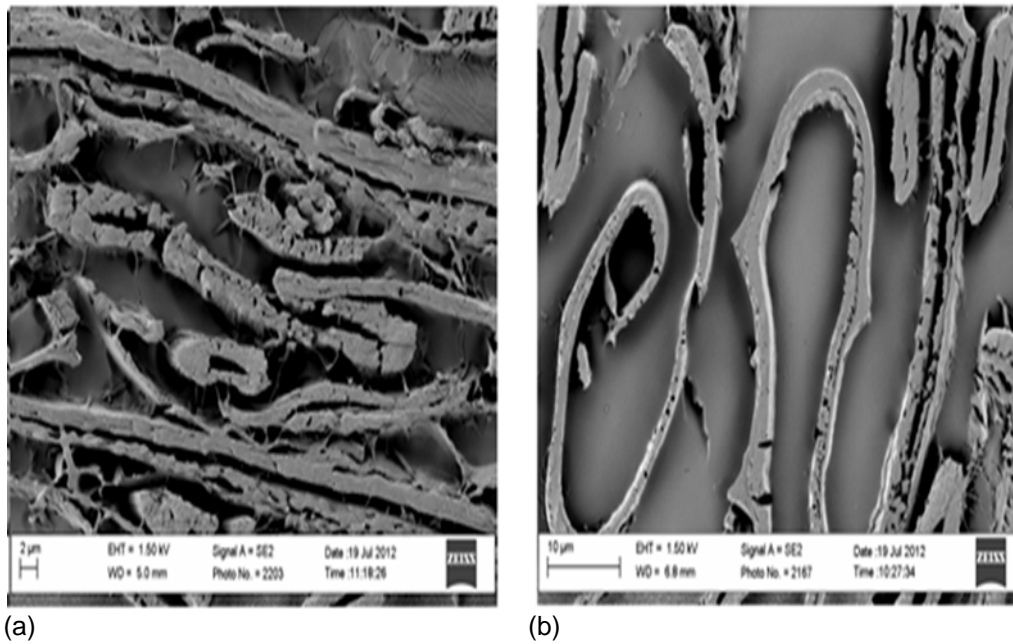


Figure 10: Photomicrographs of the accepts (a) and the rejects (b) of C+ pulp fibres

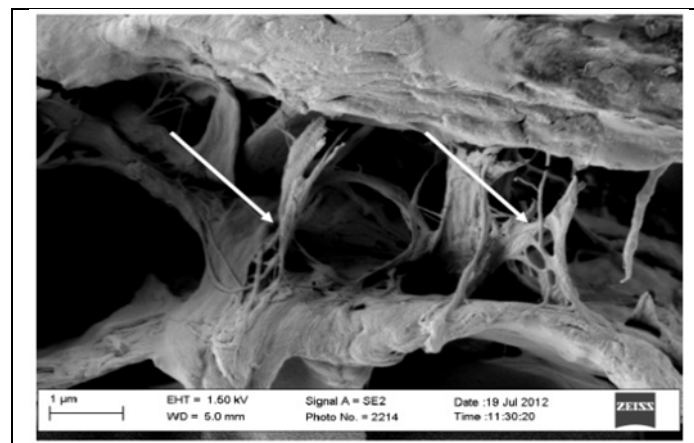


Figure 11: Photomicrograph showing the fibrillation between the C+ reject fibres

The cell wall thickness of C+ hydrocyclone treated pulp fibres as determined by the MorFi fibre analyser are shown in Figure 12.

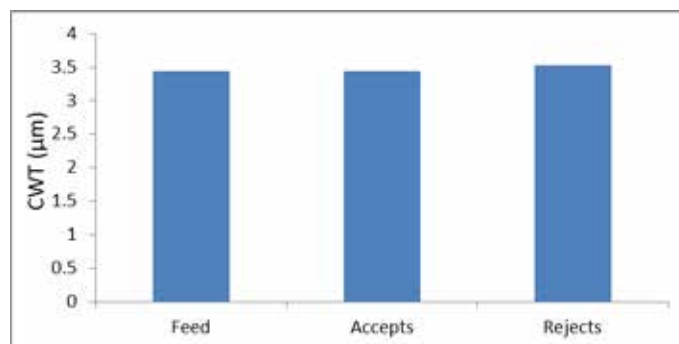


Figure 12: CWT of the feed, accepts and rejects, of C+ pulp

5. DISCUSSION

5.1. Hydrocyclone

It was found that HL1 at a consistency of 0.2% gave the best fractionation efficiency using the hydrocyclone. A mass reject ratio of 0.3 gave the highest fractionation index, while a mass reject ratio of 0.4 provided the most efficient separation in terms of tensile strength. When C+ was passed through the hydrocyclone, at a consistency of 0.2% and mass reject ratio of 0.4, it gave the best fractionation efficiency in terms of tensile strength. FEG-SEM analysis of C+ showed that the hydrocyclone was fractionating mainly on the basis of the degree of fibre fibrillation rather than cell wall thickness (CWT). It was found that the accepts fraction of the hydrocyclone contained the more fibrillated fibres, when compared with the rejects. This resulted in the tensile strength index of the accepts being higher than that of the feed and rejects before refining.

5.2. Pressure Screen

Heavy letter one was screened through the pressure screen at slotted screen sizes of 0.2 mm and 0.25 mm. The highest overall fractionation index, of 0.46, was achieved at a slot size of 0.2 mm and mass reject ratio of 0.81. Fractionation indices of the pressure screen were higher than those obtained for the hydrocyclone, for HL1. Strength properties were erratic due to the high consistency and variability of raw material. The highest fractionation index of 0.21 was achieved at a mass reject ratio of 0.89 for C+ pulp. The tensile index of the C+ accepts was similar to the feed and greater than the rejects before refining.

5.3. Refining

There was an increase in tensile with an increase in refining of the rejects for both pulps. The hydrocyclone rejects showed a greater increase in tensile strength when compared to the refined rejects from the pressure screen. Heavy letter one pulp had a greater increase in tensile when compared to C+ pulp. When compared to virgin fibre, the tensile strength of HL1 pulp, at a beating level of 5 000 revs, was approximately the same as the tensile strength of unrefined softwood. The unrefined hardwood tensile strength was still higher. In both cases the recombined stock showed an overall improvement of strength properties from the feed.

Comparison of HL1 and C+ feed properties revealed that there was no statistical difference between the fibre length, tensile, tear and burst strengths of the two raw materials.

5.4 Field Emission Gun Scanning Electron Microscope (FEG-SEM) and cell wall thickness (CWT) analyses.

The FEG-SEM analysis gave an idea of the physical structures of the fibres in the accepts and rejects streams which manifested themselves in a higher and lower tensile strength in the accepts and rejects streams respectively. This was ascribed to the higher degree of collapsibility and fibrillation of the accepts fibres.

There was no distinguishable difference in CWT between the feed, accepts and rejects fibres and therefore the separation in the hydrocyclone is not based on differences in CWT.

6. CONCLUSIONS AND RECOMMENDATIONS

The hydrocyclone was found to be the best method for fractionating both the C+ and HL1 grades of recovered paper, to obtain a short fibre (accepts) fraction with higher tensile strength properties than the unfractionated samples.

Refining of the rejects of HL1 and C+ from the hydrocyclone trials in a PFI mill resulted in tensile strengths almost equal to that of unrefined virgin softwood fibre at a beating level of 5 000 revolutions. The HL1 tensile strength was higher than that of C+ after beating at 5 000 revolutions in a PFI mill.

Recombining the refined rejects with the unrefined accepts from both the hydrocyclone and screen trials, resulted in a superior quality pulp with respect to tensile strength, than the unfractionated resource for both C+ and HL1 pulps.

Separation in the hydrocyclone is not based on differences in CWT, but more on degree of fibrillation

It is recommended that HL1 and C+ pulps undergo the staining tests to distinguish between chemical, mechanical and sulphite fibres. The test should be done on the original feed and the accepts and rejects from both the hydrocyclone and pressure screen. This would show how well each piece of equipment fractionated the different types of pulps.

Pressure screen trials at lower consistencies and using different screen and rotor combinations should be tried to determine the most effective screening parameters for fractionation. Unfortunately, in this trial, it was not possible to change the consistency of the feed.

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