5 Methods used to vary fibre and sheet properties

5.1 Introduction

In order to verify the theory for tensile strength of paper, experiments were carried out trying to vary only one property of the fibres or paper and keep the other properties constant. In this project, we used hydrocyclone fractionation to generate fibre fractions with different fibre cross-sectional shape but approximately the same fibre length. We used cutting wet handsheets to generate fibre fractions with different fibre length but the same fibre cross-sectional dimensions and shape. We used wet pressing to vary the sheet density or the degree of bonding of the sheets. These experiments and the properties of the fibre fractions generated by these experiments are discussed in this chapter. The starting material for all these experiments was the never dried low kappa (30) pulp described in Appendix A2. This was a new pulp that was specially prepared for these experiments after the high kappa pulp used in Chapter 4 was found to contain too many shives.

5.2 Experimental methods

5.2.1 Wet pressing

The purpose of the wet pressing experiment is to generate sheet with different tensile strength but not to significantly affect the properties of the fibres in the sheets.

Most of the handsheets made in this project were pressed dynamically using a Sheet Roller Press. Only the handsheets from the fractions generated by cutting wet handsheets were pressed statically using a hydraulic pressing machine.

Pressing the sheets dynamically involved placing the plate, sheet and blotter between two press felts which were then passed through a roller press a number of times, as illustrated schematically in Figure 5-1. For the size of the handsheets used in this project, the pressing load applied on the sheets can be calculated using the chart shown in Figure 5-2.

In the static pressing experiments, each handsheet, sandwiched between blotters and an iron plate, was pressed for 2 minutes so that the handsheet was transferred to the iron plate.

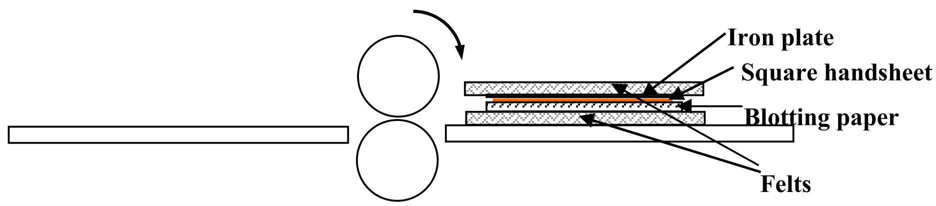

Figure 5-1 Schematic diagram of the Roller Sheet Press (drawing not to scale)

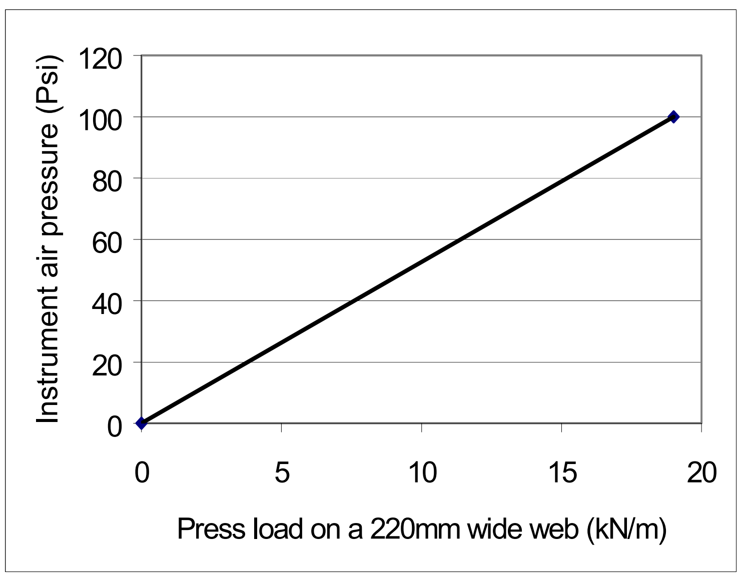

Figure 5-2 Pressure conversion from the instrument air pressure to press load on paper

In both of the dynamic and the static pressing experiments, handsheets were pressed at one of five pressing levels as given in Figure 5-1. These sheets were then dried under restraint in a conditioned test room (23ºC, 50%RH).

Table 5-1 PRESSING LOAD AND PRESSURE FOR DYNAMIC AND STATIC PRESSING

Press level	Dynamic press load (kN/m)	Static press pressure (kPa)
P_1	0*	100
P_2	3.0	200
P_3	7.0	500
P_4	3.0 + 10.0×2 passes	2000
P_5	3.0 + 10.0 + 20.0×10 passes	4000

*"0" represents pressing with no additional force applied to the rollers.

5.2.2 Fractionation – for generating fibre fractions with different cross-sectional shapes

Previous studies of hydrocyclone fractionation show that hydrocyclones can be used to separate chemical pulp effectively into accepts and rejects fractions with different cross-sectional properties (Gavelin 1991; Paavilainen 1993; Rehmat 1995; Li 1999). In earlier studies (Gavelin 1991; Rehmat 1995), fibre length and coarseness were claimed to be the key properties affecting the separation. Paavilainen (Paavilainen 1993) showed empirically that, for softwood pulps, the fibre wall thicknesses are significantly different for fibres in the accept and reject fractions from hydrocyclone fractionation. Recently, Li et al. (Li 1999) studied the mechanism of hydrocyclone fractionation systematically. They demonstrated that the 'apparent density' of fibres is the major factor controlling the hydrocyclone separation. An apparent density factor was defined and used to describe the efficiency of hydrocyclone separation. The derivation of the apparent density factor begins by idealising a fibre as a tube. The fibre wall area, A_f, for an ideal tubular-shaped fibre can be calculated from the outer diameter D_0 and the lumen diameter d_0 by the following equation.

$$A_f = \pi(D_0 - d_0)/4 \qquad \textbf{5. 1}$$

The apparent density factor is then given by the following equation.

$$AD = 4\pi A_f / P_0^2 = (D_0 - d_0)/D_0^2 \qquad \textbf{5. 2}$$

where AD is the apparent density factor and P_0 is outer perimeter.

The value of AD is can be calculated by measuring the perimeter and the wall area of the dry fibre according to its definition by Equation 5.2.

In physical terms, AD represents the fraction of the cross-sectional area of an idealized dry fibre cylinder occupied by the cell wall. When the fibre approaches a solid cylinder, AD approaches its maximum value of 1. When the fibre becomes more open AD decreases.

An AKW (Amberger Kaolinwerke Gmbh) 40mm cyclone was used to do the fractionation. The hydrocyclone test rig used in the experiment is illustrated in Figure 5-3. The rig consists of an AKW cyclone, a flow meter measuring in milli ampere, a mono pump and a stock tank. A container with a 200 mesh screen on the bottom is not shown in this Figure.

Two fractionation runs were conducted with the low kappa pulp. 100g of pulp was fractionated for each run. The mass split between the accepts and the rejects was set to be 9 to 1 for each run. The unit was running at 0.1% pulp consistency, which was found to give the best efficiency of separation by the AKW cyclone in a study by Mattson (Mattson 2001). The inlet flow rate was set at 0.2 mA, which was approximately 8 kilograms per second as one milli ampere was equal to 4 kilograms per second. The separated accept and reject fractions were each collected by drainage through a 200 mesh screen so that fines in these fractions have been removed before they were used in subsequent experiments. During the fractionation the stock tank was constantly refilled with fresh water so as to keep the level in the tank constant. A two-stage fractionation was carried out in the experiment in order to obtain good separation results. Figure 5.4 illustrates the procedure used.

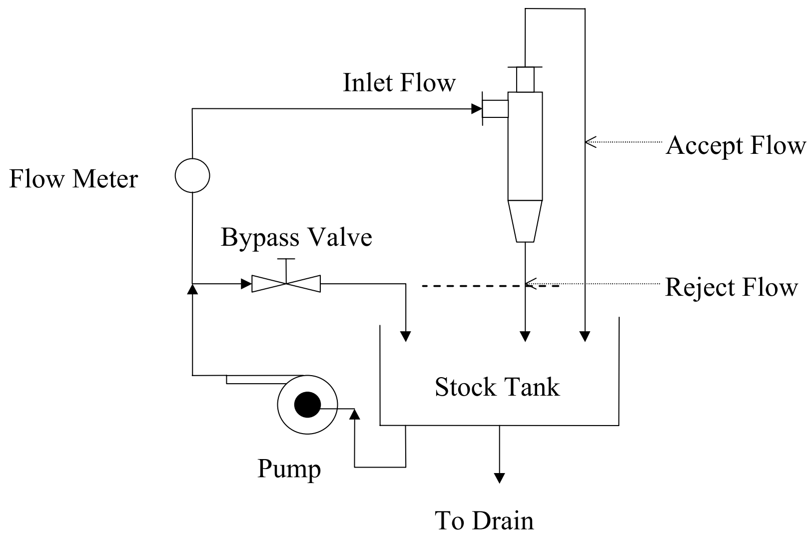

Figure 5-3 Hydrocyclone unit used in the fractionation experiment.

The final accept fraction was ‘fraction AA’ shown in Figure 5-4 and the reject fraction was ‘fraction RR’. The fractions AA and RR were treated as the accepts and the rejects used in the subsequent experiment.

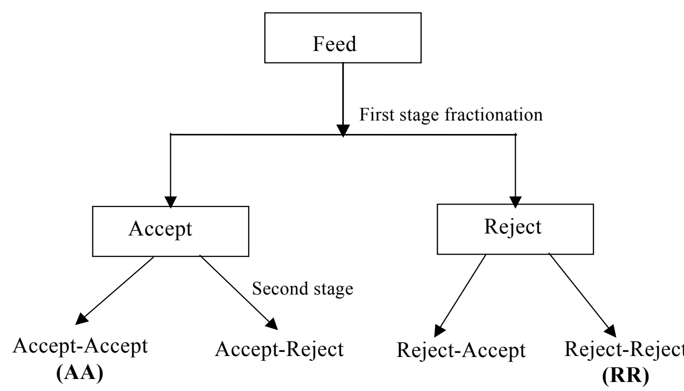

Figure 5-4 Procedure of the two-stage fractionation

AD given in Equation 5.2 was used to evaluate the fibre separation occurring in the hydrocyclone. The AD factors of the accepts and rejects were determined from measurement of the perimeter and wall area of fibres deposited on glass slides using the confocal microscope following the method described in (Li 1999). Figure 5-5 shows the cumulative distributions of the AD factors of the accepts and rejects fractions. The means of the AD factors of the accepts and the rejects are 0.50 and 0.57 respectively. Statistical analysis shows that the AD factors of the accepts and the rejects are significantly different at a 99.5% confidence level. This indicates that the pulp fibres have been separated on the basis of different cross-sectional shape by the hydrocyclone operation. The length weighted fibre lengths of the accepts and the rejects are 2.42mm and 2.24mm. this compares with a length weight fibre length of the starting stock of mm. The fibre lengths of both accepts and rejects are somewhat higher than the starting stock due to the loss of fines in the filtering process.

Five sets of $60g/m^2$ square handsheets were made from the accepts and the rejects respectively on a Moving Belt Sheet Former (see Appendix A). The apparent density of the handsheets were varied by pressing dynamically using the roller press at one of the 5 different pressing levels as shown in Table 5-1. The apparent density, as a function of pressing level, of handsheets of the accepts and the rejects from the low kappa pulp is shown in Figure 5-6. It can be seen that the sheet density of the accepts is up to $100kg/m^3$ higher than handsheets made from the rejects. The difference in sheet density confirms that significant separation has been achieved in the hydrocyclone.

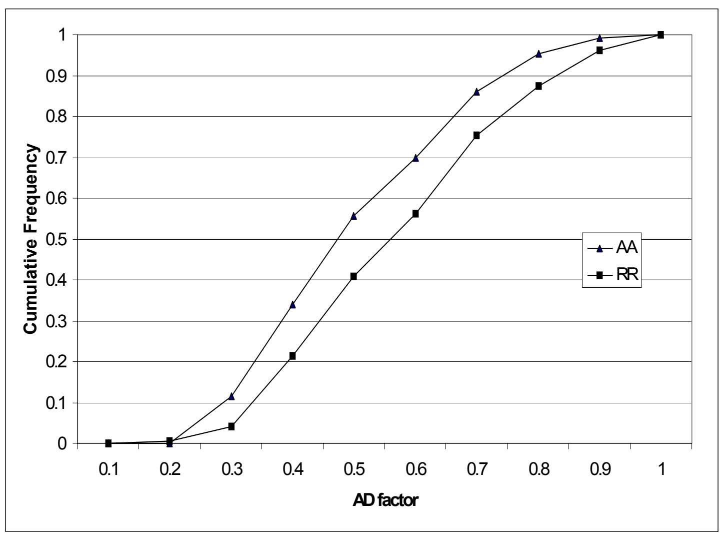

Figure 5-5 Cumulative distributions of AD factor of the accepts and the rejects

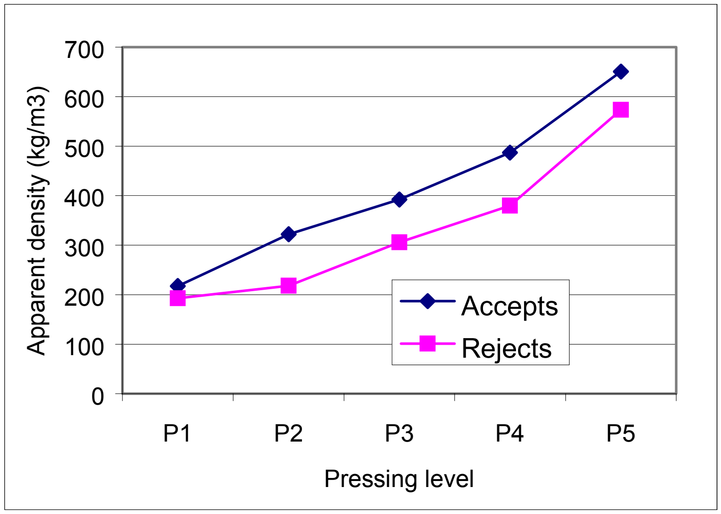

Figure 5-6 Apparent density of handsheets made from the fractionated low kappa pulp where the density has been varied by dynamic pressing at different pressing levels.

5.2.3 Cutting wet handsheets – for generating fibre fractions with different fibre length

This experiment aimed to vary fibre length only while keeping the other properties of fibre constant. Four fibre fractions with different fibre lengths were produced (L_0, L_1, L_2, L_3) with ever decreasing fibre length. The L_0 fraction was not cut and is the starting low kappa pulp from which all the other fractions were produced.

Wet handsheets were cut, immediately after they were formed on a Moving Belt Sheet Former (MBSF), using a specifically designed die (see Figure 5-7) to generate fractions of fibres differing only in the fibre length. The blades of the die are very sharp and thin so that the compression effects on the fibres during cutting have been minimized. The fibre ends generated by the cutting operation were carefully examined in the confocal microscope. As shown in Figure 5-8, no compression can be seen at the cut end.

In the cutting operation, the die was placed blade side down (Front view) on several wet sheets and impact pressed. Four fractions of fibres with different fibre length were then created as L_0: uncut fibres, L_1: cut once in one blade direction, L_2: cut twice, with the die being rotated 90° between cuts, L_3: cut wet handsheets made from L_2. The fibre length of the four fractions was measured using a Kajaani optical fibre length analyser (see Appendix C for the full set of results).

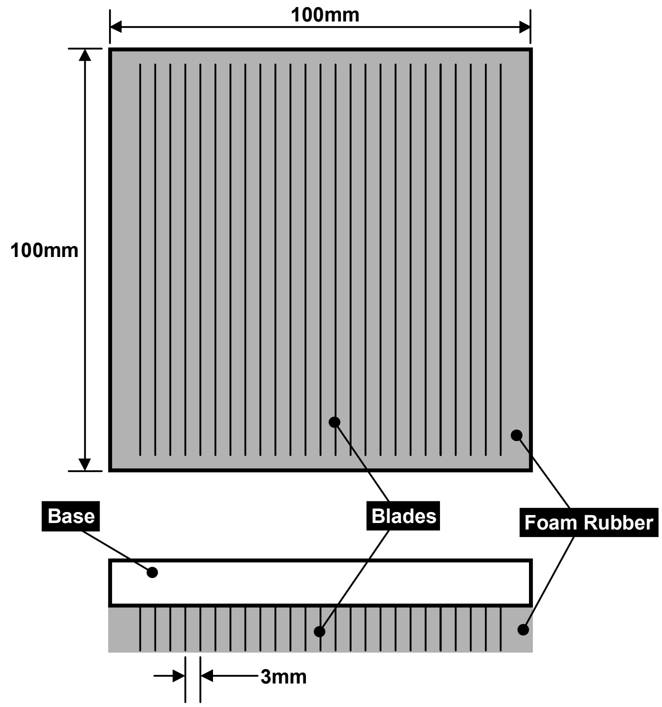

Figure 5-7 Diagram of the die used to cut wet handsheets (drawing not to scale)

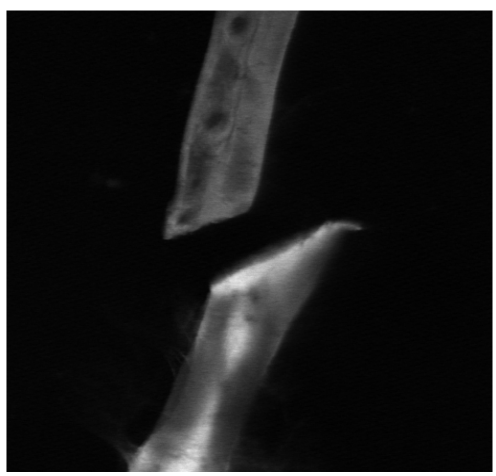

Figure 5-8 Image of fibre ends generated by the cutting operation

Figure 5-9 shows the length weighted fibre length distributions of the fibre fractions generated by cutting the wet handsheets. This method has been used in previous studies (Seth 1983; Kärenlampi 1996) and is believed to be able to change only fibre lengths while keeping other fibre dimensions constant. As shown in Figure 5-9, the length weighted fibre length distribution is shifted to a lower value range and narrowed after the fibres were cut by the above operation. The average length weighted fibre length of L_0, L_1, L_2 and L_3 are 3.14mm, 2.53mm, 2.10mm and 1.80mm, respectively. The cut wet sheets were then reslushed and formed into handsheets. These results show that fibre length has been successfully reduced by cutting the wet handsheets.

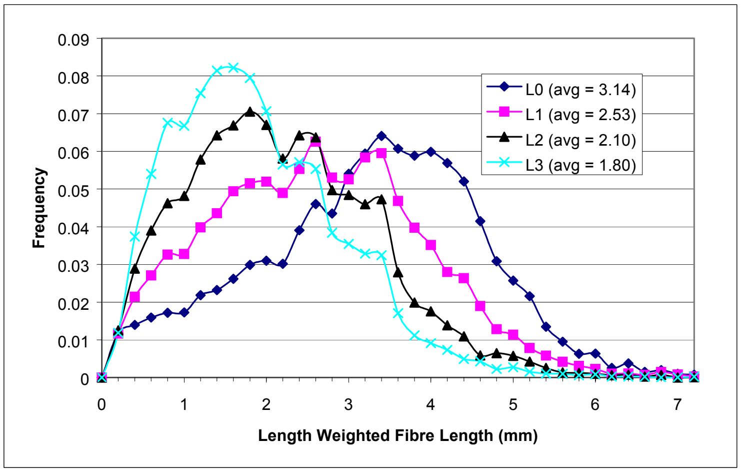

Figure 5-9 Fibre length distribution of the fractions generated by cutting wet handsheets

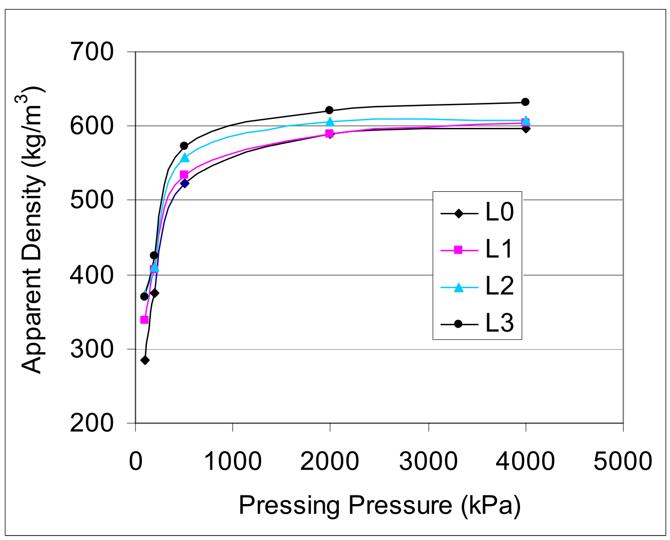

Figure 5-10 Apparent density of handsheets made from fibres with different fibre lengths where the density has been varied by static pressing at different pressing pressures.

Handsheets made from the fractions generated by cutting wet handsheets were pressed statically using a hydraulic press at one of the five pressing pressures shown in Table 5-1. The apparent density of handsheets pressed at different pressing pressures are given in Figure 5-10. As can be seen in Figure 5-10, the apparent density of the handsheets have been varied effectively by wet pressing. The data also shows a small increase in sheet density, at a given pressing pressure, as the fibre length decreases. This probably arises because the shorter fibres are better able to pack together as the sheet formes.

5.3 Conclusions

It has been shown that fibres of the low kappa pulp have been successfully separated into fibre fractions with different fibre shape. It has also shown that fibre fractions with different fibre length have been generated by cutting the wet handsheets. Examination of the fibre ends generated by the cutting operation shows that no compression effects were induced by this operation. These fibre fractions can be used in subsequent experiments for verification of theories in this project.