UNLOCKING THE NATURAL VALUE OF WOOD PULP THROUGH OPTIMIZED REFINING

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ABSTRACT

The characteristics of two wood pulps used in autoclaved fibre cement composites with specific differences in fibre coarseness and aspect ratio were compared under varied mechanical treatments.
A pilot refining study was conducted as a guide to establish effects and benefits of adjusting refining parameters to suit individual pulps according to their unique fibre morphology. A fine, SPF pulp characterised with a high fibre aspect ratio contained 60% more fibres per gram of pulp, was easier to refine and optimally treated with a low refining intensity of 1.0 W.s/m. A coarse radiata pulp with lower aspect ratio and fibre density was best treated using a higher refining intensity of 2.5 W.s/m. Optimum refined properties were achieved with the fine pulp delivering longer, stronger fibres with a 20% higher stiffness. Refining the fine pulp at a higher 2.5 W.s/m intensity provides an opportunity to reduce energy costs by up to 35%.

KEYWORDS:

Refining, UBK, Coarseness, Autoclaved fibre cement

INTRODUCTION

The use of cellulose fibres as a replacement for asbestos in fibre reinforced composites (FRC) has been adopted and successfully applied for many years in Australia, New Zealand, South Africa, USA and parts of Europe (Banthia, 1998). With a variety of wood pulps on the market, procurement teams generally select suitable pulp grades based on the price, availability and fibre morphology of the raw pulp. From a technical perspective, for autoclaved fibre cement products, ideal wood pulps have many long, strong fibres with a low and consistent lignin content.

Leading pulp manufacturers often run pilot refining studies to benchmark and optimise pulp properties with testing procedures and specifications typically targeted towards paper grade applications. Pulp requirements for FRC may differ to that of paper grades but the refining equipment used to develop the fibres is the same. Results and findings from such pilot refining studies do however provide useful information on the changes in fibre morphology and relative refining behaviour of different market pulps used in fibre cement products. Understanding a particular pulps response to varied mechanical treatments is an important factor that ultimately defines the value it adds to the end product. To optimize pulp quality, any change in the pulp type or blend ratio should be aligned with an appropriate adjustment to the refining conditions.

This study measured and quantified the unrefined constituents of two Unbleached Kraft (UBK) market pulps widely used in the fibre cement industry and characterised subsequent changes in fibre morphology and physical properties through a pilot refining study. The effects of varied mechanical treatments on the two pulps with a significant difference in fibre coarseness and aspect ratio was established as a guide towards optimum fibre development for different pulps used in fibre cement applications.

EXPERIMENTAL DESIGN

Two Kraft market pulps commonly used in fibre cement grades with a significant difference in fibre coarseness were selected for evaluation. The samples included a fine, low coarseness spruce, pine, fir (SPF) pulp from the interior of British Columbia and a coarser southern radiata pine pulp from Chile.

During the evaluation, raw pulp sheets of both samples were tested to establish relative differences in the chemical make-up and fibre morphology as received. A Voith LR40 single disc pilot refiner (Fig. 1) was then used to treat both pulps accurately simulating refining forces applied in the field.

Figure 1 - Voith LR40 Refiner (Linblad 2013)

Previous studies (Linblad, 2013) have shown the Voith LR40 pilot refiner to be more representative of mill refiners with good repeatability in refined strength development compared to the traditional PFI Mill.

Both the fine and coarse pulps were refined under identical conditions in hydra-cycle mode using a single set of softwood refiner plates (3 mm bar width, 5 mm groove width with a 60^0 cutting angle) with varied energy and intensity settings. Two refining intensities of 1.0 W.s/m and 2.5 W.s/m were set and controlled according to a fixed applied load. Refined pulps were auto sampled at increasing energy levels ranging between 0 and 250 kWh/t according to pre-determined time intervals as the pulp continually cycled across the refiner at a fixed consistency and flow throughput.

The fibre morphology of the refined pulps was measured and 60 gsm handsheets made to establish the effect of mechanical treatments on physical properties typically measured for a wide range of paper products.

It is noted that reported results are not purely indicative of the specific wood species but are also highly influenced by combined effects of the geographic location of the timber, environmental growing conditions, residual vs. whole tree chips and pulping and pulp processing. Furthermore, reported physical properties relevant to paper grade requirements may not show a direct correlation to fibre cement properties but do serve as a guide on the relative changes affected by refining.

PULP CHARACTERIZATION

Wood in general is extremely heterogeneous and despite the use of modern pulping technology and intensive quality control measures, no two pulps are identical in nature. Understanding the characteristics of the pulp being used is a critical factor having a significant influence on the final product quality. Certain pulp grades may appear to be similar when comparing general pulp property data sheets however this could be misleading given possible differences in measurement methods, PFI vs disc refining data and averaged typical results within a wide range.

PULP CHEMICAL COMPONENTS

The primary objective with Kraft pulping is to effectively remove lignin from the woody matrix to liberate individual fibres without degrading the cellulose and reducing pulp strength. Kraft pulp mills typically measure and control the lignin content of the pulp according to a target kappa number.

The lignin content of the two pulps was measured using two different test methods, firstly by lignin oxidation using the Tappi T236 Kappa method commonly used in pulp mills, and secondly by the Tappi T222 Klason Lignin method measuring the acid insoluble lignin content. Both test methods indicated a lower lignin content in the fine SPF pulp (Table 1) which is expected to result in a lower refining energy requirement. The fine pulp also exhibited a slightly higher cellulose content and lower hemicellulose content compared to the coarse pulp. Wood pulps with higher levels of lignin and hemicellulose have been noted to negatively effect the hydration of cement composites.

Table 1: Chemical constituents of SPF and radiata pine pulps

	Fine pulp (SPF)	Coarse pulp (Radiata)
Kappa Number	26	38
Cellulose	78%	76.7%
Hemicellulose	11.9%	13.1%
Klason Lignin	6.8%	7.3%
Ash	0.4%	0.5%

CELLULOSE DEGRADATION, INTERFIBRE FIBRE BONDING AND CLEANLINESS

Viscosity test results measured according to the Tappi T-230 test method (Table 2) showed the fine pulp had a higher viscosity indicating a higher cellulose molecular weight and less cellulose degradation from the pulping process. Pulmac zero span strength tests performed on the samples as received showed the fine pulp had stronger fibres and better bonding properties compared to the coarse pulp.

Table 2: Test results on raw pulp strength and bonding properties

	Viscosity	Wet Zero Span	Dry Zero Span
	cP	km	Km
Fine pulp	38.8	13.4	15.2
Coarse pulp	27.2	13.1	12.5

Table 3: Cleanliness, dirt and shive content of the raw pulps

	Dirt	Shive Content	Extract Conductivity
	ppm	#/g	µS/cm
Fine pulp	1.3	472	21.2
Coarse pulp	2.1	1272	108

Contaminant measurements (Table 3) showed similar dirt content for both pulps. The coarse pulp had a higher shive count and extract conductivity as expected with the higher lignin content.

Table 4: Alkaline solubility of the raw pulps

S 18	Alkaline Solubility (%)
Fine pulp	11.9
Coarse pulp	13.6

The alkaline nature of the fibre cement process creates a harsh environment with a high risk of cellulose degradation. An S18 alkaline solubility test conducted on both pulps showed the fine pulp was more resistant to alkalinity displaying a slightly lower solubility than the coarse pulp (Table 4).

PULP FIBRE MORPHOLOGY

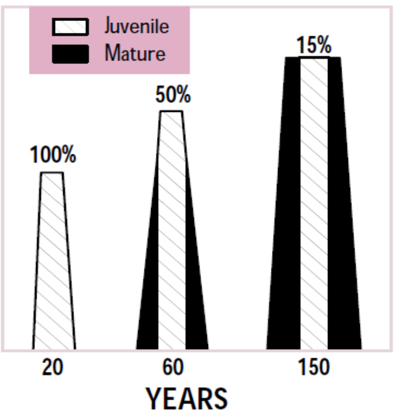
The fibre morphology of the cellulose fibres as the primary pulp constituent largely defines the pulp strength and its response to mechanical treatment.

Table 5: Fibre morphology of unrefined pulps

	Units	Fine pulp	Coarse pulp
Average Weighted Fibre Length	µm	2590	2580
Average Weighted Fibre Width	µm	29.8	34.6
Aspect Ratio (Fibre Length / Fibre Diameter)		173	149
Average Weighted Fibre Wall Thickness (confocal microscopy)	µm	1.72	2.21
Coarseness	mg/100m	13.3	21.4
Fibres per gram		290082	180613

The average weighted fibre dimensions of the unrefined pulps was measured and compared optically by an L&W fibre tester and confocal microscopy (fibre wall thickness).The fine pulp was characterized with a relatively high number of long, narrow fibres with a thin fibre wall thickness, low coarseness and high aspect ratio (Table 5). It is likely the fine pulp with 60% more fibres per gram of pulp will allow for better dispersion and interfacial bonding of the fibres with the cementitious matrix and should also improve the strength of the composite after cracking through a greater number of bridging points that transfers the load. In general, the relative performance of wood pulps in fibre cement composites is compared on an equivalent mass basis. Future studies evaluating pulps with different aspect ratios added at an equivalent fibre number per gram of pulp is recommended.

A key factor to consider with this SPF fine pulp is that it is made from residual wood chips sourced from the outer periphery of older trees (>100yrs) and therefore contains mostly mature wood (Fig. 2). Sourcing fibres in this manner ensures a uniform quality with a smaller range in fibre length and width (Fig 4 and 5).



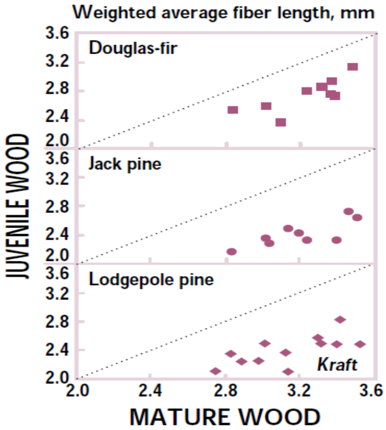


Figure 2 – Location of juvenile & mature wood (Hatton 1997)

Figure 3 –Fibre length of juvenile & mature wood (Hatton 1997)

In contrast, the coarse pulp is produced mostly from whole trees and is typically felled under short rotations (<20yrs) and therefor includes a combination of juvenile and mature wood fibres, hence the wider distribution in fibre morphology.

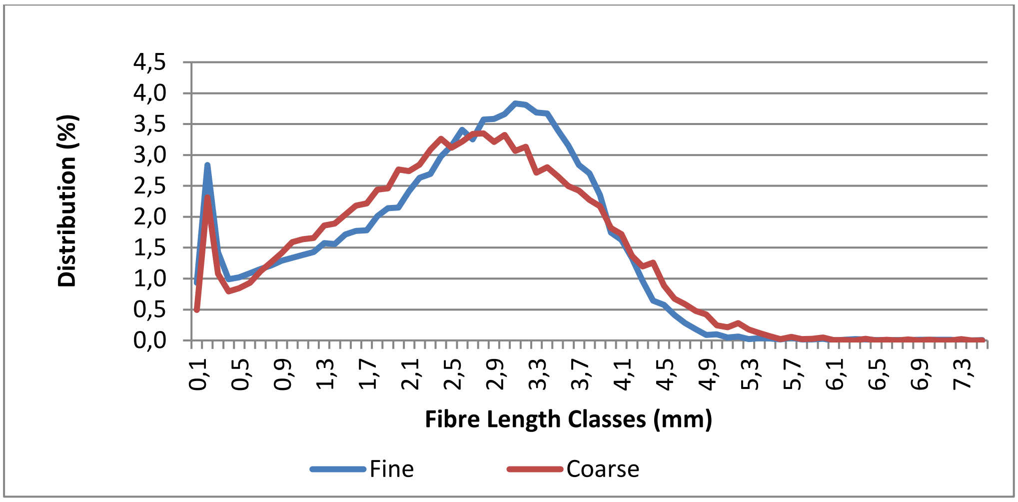


Figure 4 - Fibre length distribution of unrefined fine and coarse pulps

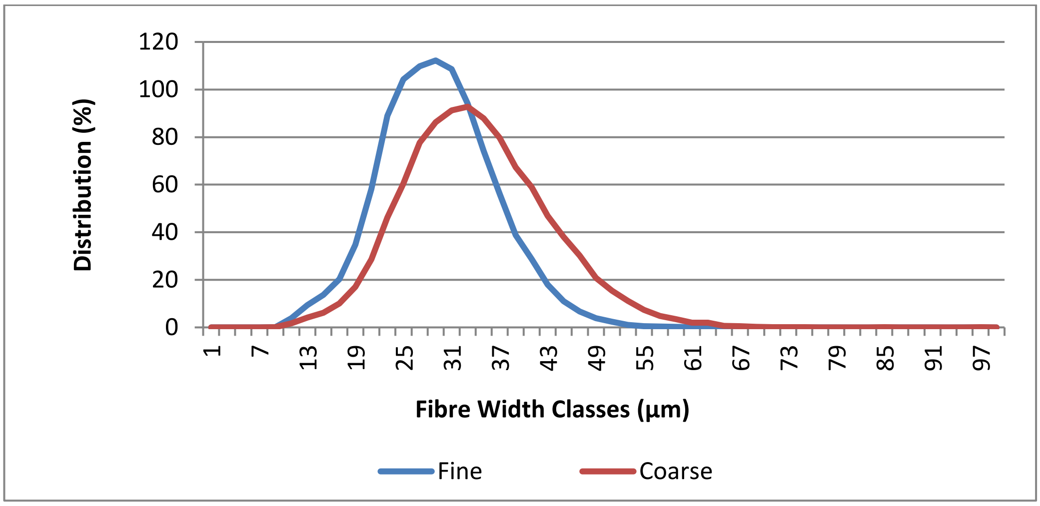


Figure 5 – Fibre width distribution of unrefined fine and coarse pulp

The electron photomicrographs shown in figures 6 and 7 of handsheets made from each of the two pulps highlights the higher fibre density and collapsibility of the fine pulp.

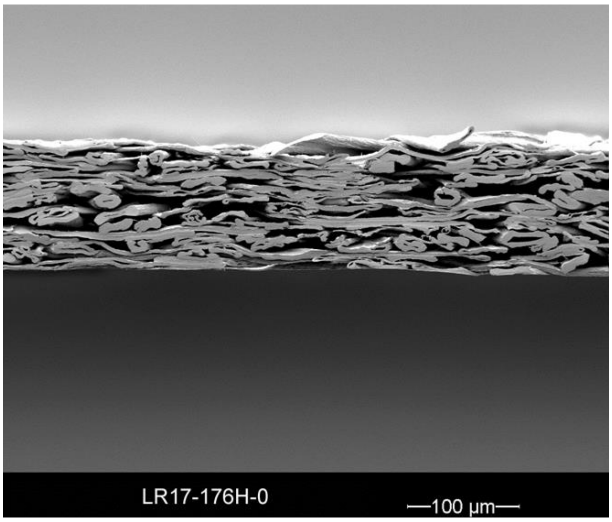


Fig 6. SEM Cross section of unrefined fine pulp

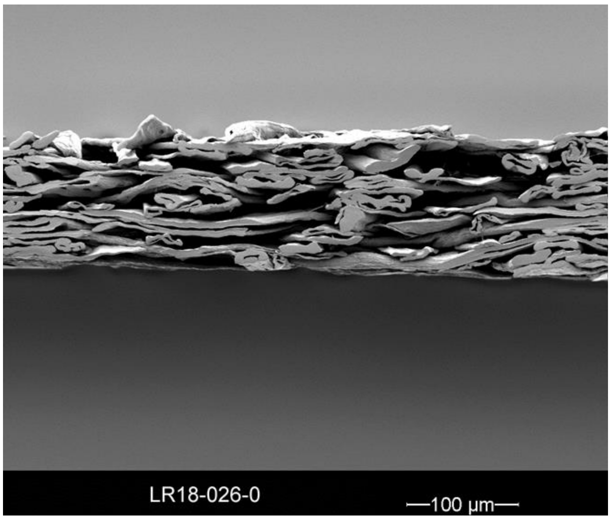


Fig 7. SEM cross section of unrefined coarse pulp

REFINING VARIABLES AND CONTROLS

To extract maximum value, wood pulps need to be optimally refined to enhance fibre development whilst minimizing the negative effects of reduced drainage and fibre cutting.

Refining is an art in itself with many variables that significantly influence the quality of the refined pulp. Factors such as refiner plate design, refiner motor rpm, pulp flow and consistency, inlet and outlet refiner pressure and refining load amongst other parameters all have an effect that differs according to the pulp that is being refined. In general however, the refining load and intensity are two key variables mostly used to define and characterize the overall refining treatment.

The applied refining load relates to the effective energy applied to the pulp moving between refiner plates. The actual gap between the rotor and stator plates relates to the applied load and is controlled purely on the power output of the refiner, as indicated by amps or kW or, more ideally, the power that is applied relative to the flow and consistency of the pulp passing through the refiner, termed specific refining energy. Units for specific refining energy are kilowatt hours per dry ton of pulp (kWh/t) or horsepower days per dry ton of pulp (HpD/T).

The refining intensity, termed Specific Edge Load (SEL) considers plate design, refiner motor rpm and applied energy in units of watt seconds per meter (W.s/m) or joules per meter (Wahren. D) and defines the impact level of refiner plate bars on passing fibres. In practice, refining intensity is altered by changing plate design, refining energy and using more or less refiners in series. When looking to adjust refining intensity, production personnel generally choose to install a different plate design involving a change in the cutting length of the bars where, for example, refiner plates with a longer cutting length gives a lower refining intensity and a more gentle fibre treatment.

In most cases, mill refiners are controlled according to a refined pulp freeness target as freeness is a quick and easy test to measure and control the level of refining. This however is not ideal as refining is primarily applied to enhance strength and bonding with reduced freeness (slower drainage) as a secondary and undesired effect.

EFFECT OF VARIED REFINING PARAMETERS

This study evaluated the effects of two intensities at 1.0 W.s/m and 2.5 W.s/m over a wide refining energy range of 0 kWh/t to 250 kWh/t. The aim was to establish the relative effects on freeness, fibre length, energy use and fibre development on the two selected pulps.

As expected, results indicated the fine pulp with the low coarseness fibres and lower lignin content was more receptive to mechanical treatment exhibiting a steeper fall in freeness for a given energy (Fig. 8). For both pulps, higher refining intensities lead to a sharper reduction in freeness for a given refining energy. The target refined pulp freeness range for autoclaved products varies between manufactures but for the purposes of this comparative study a refined freeness ranging between 340 and 420 ml CSF was selected. Results showed the coarse pulp required a high refining intensity of 2.5 W.s/m to reach the freeness target whilst the fine pulp achieved the target at both the 1.0 and 2.5 W.s/m intensities. Using the fine pulp and refining it at the higher 2.5 W.s/m intensity provides an opportunity to reduce energy costs by up to 35%.

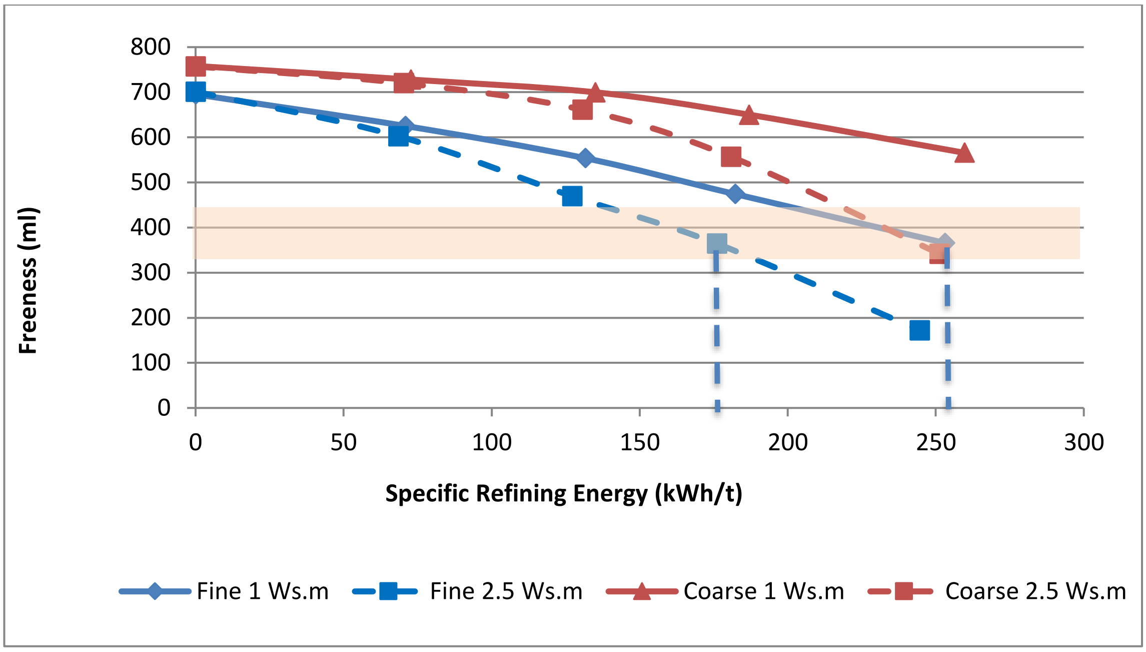


Figure 8 - Refined freeness development of fine and coarse pulps

The preservation of fibre length through the refining process is a key factor considering the initial pulp selection favors pulps with long fibres. There is no advantage in paying for long fibres and then cutting them into short lengths before mixing with the other blend partners.

Fibre length measurements on the refined pulps (Fig. 9) highlighted the benefits of adjusting refining parameters to suit different pulps. In this study only the samples falling within the targeted refined freeness range were evaluated.

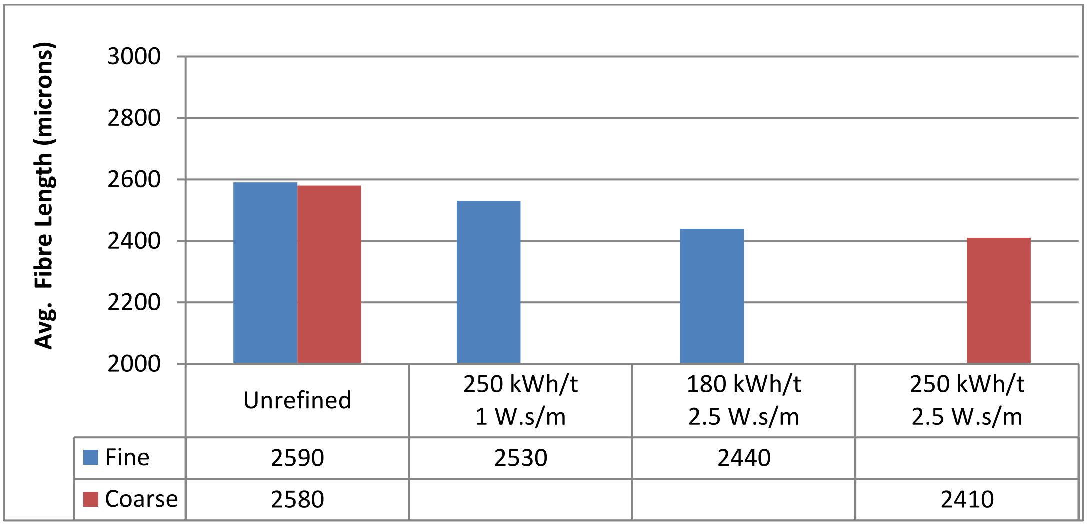


Figure 9 - Effect of refining on the fibre length of fine and coarse pulp

The longest refined fibre length at the target freeness was recorded with the fine pulp when refined at the lower 1.0 W.s/m intensity using 250 kWh/t. When the fine pulp was refined at the higher 2.5 W.s/m intensity the required refining energy dropped from 250 kWh/t to 180 kwh/t (35% reduction) to reach the target freeness however, this was associated with an increase in fibre cutting down to shorter fibre lengths. For the coarse pulp, the target freeness could only be achieved at the higher intensity of 2.5 W.s/m using 250 kWh/t and delivered the shortest fibres.

Considering the target freeness and fibre length results at the two selected intensities, it appears 1.0 W.s/m is better suited to the low coarseness pulp whilst 2.5 W.s/m is best for the coarse pulp. In cases where there is limited refining capacity or where energy costs are high, the best approach may be to rather use the fine pulp at the higher refining intensity of 2.5 W.s/m which uses less refining energy at the expense of fibre length and strength development.

Softwood pulp producers generally optimize fibre quality using breaking length and tear index as a guide to enhance the strength potential of pulps. In this assessment the quality of the two pulps was evaluated by measuring the relative breaking length, stiffness and zero span fibre strength of the two samples refined to the target freeness.

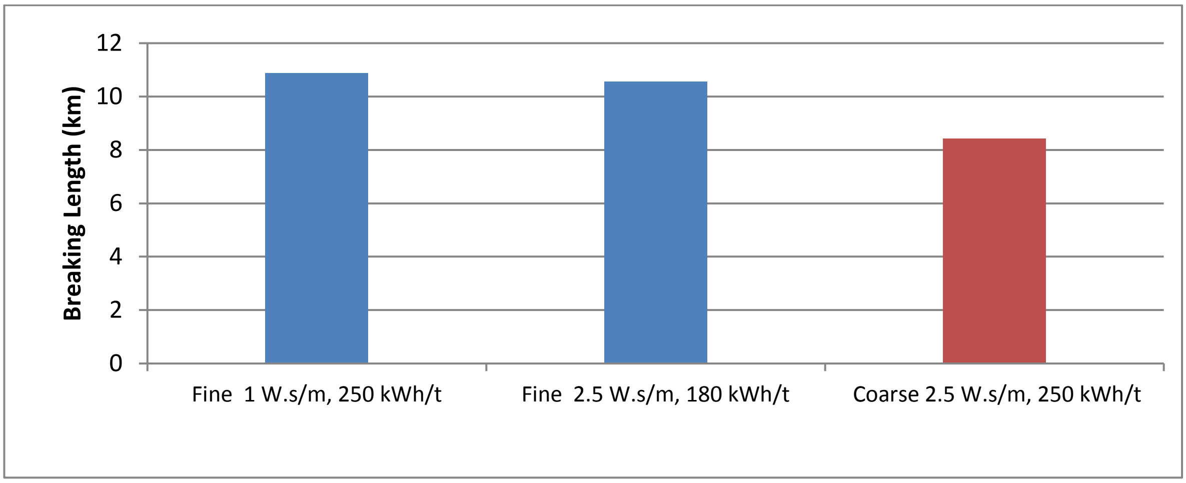


Figure 10 - Refined breaking length at target freeness for fine and coarse pulps

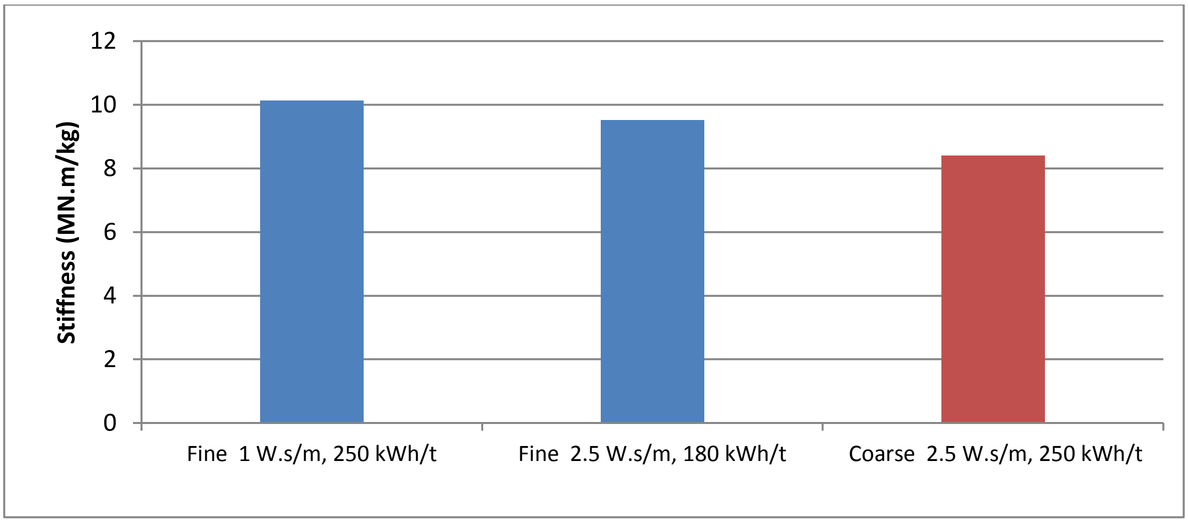


Figure 11 - Refined stiffness at target freeness for fine and coarse pulps

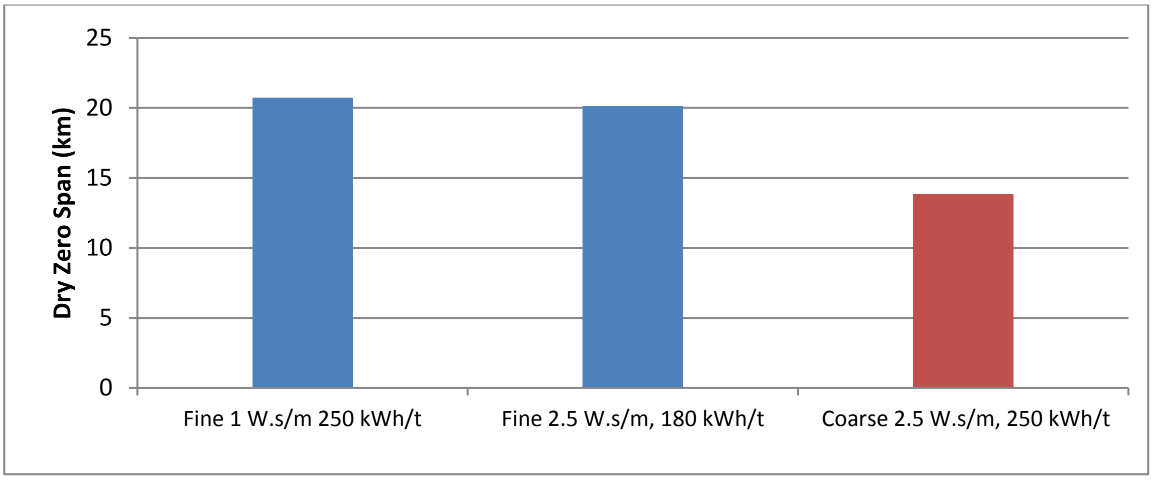


Figure 12 - Refined dry zero span at target freeness for fine and coarse pulps

The fine pulp exhibited a higher refined breaking length, stiffness and dry zero span strength (figs. 10,11 and 12) relative to the coarse pulp. Good breaking length is driven by the higher number of fibres, and increased fibre fibrillation with refining whilst the stiffness and dry zero span results are more indicative of individual fibre strength. In general, refining the fine pulp at the low 1.0 W.s/m intensity delivered slightly higher strengths than that refined at the higher 2.5 W.s/m. Results suggest low intensity refining enhances both the individual fibre strength and bonding characteristics of fine pulps which can be used as a guide for optimized use in fibre cement applications.

For optimum pulp strength development and preservation of fibre length, the fine pulp is best refined at a low intensity of 1.0 W.s/m. The coarse pulp is best refined at a higher intensity of 2.5 W.s/m (Table 6).

Table 6: Summary of refined pulp characteristics of the incoming pulp at the target freeness

	Freeness	Ref. energy	Fibre Length (µm)		Break Length (km)		Stiffness (mN.m/kg)	
	CSF (ml)	kWh/t	Initial	Refined	Initial	Refined	Initial	Refined
Fine 1 W.s/m	366	250	2590	2530	4.2	10.9	6.5	10.1
Fine 2.5 W.s/m	364	180	2590	2440	4.2	10.6	6.5	9.5
Coarse 2.5 W.s/m	341	250	2580	2410	2.2	8.4	4.5	8.4

CONCLUSION

The initial selection of suitable market pulps for autoclaved fibre cement composites has a major influence on properties of the final product. Significant benefits in improved product strength or reduced energy costs stand to be gained by optimizing downstream refining parameters to suit the characteristics of the incoming fibre.

In terms of general fibre strength and pulp quality typically measured for paper grades, the fine, SPF pulp with a high fibre aspect ratio and fibre density delivered long, strong fibres with a 20% higher stiffness when optimally refined at a low intensity of 1 W.s/m. The coarse radiata pulp with a lower aspect ratio and fibre number required a higher refining intensity of 2.5 W.s/m to meet the targeted freeness. Should energy savings be a primary driver, the fine SPF pulp should be added and refined with a higher intensity of 2.5 W.s/m delivering a 35% energy saving at the slight expense of fibre length and stiffness.

Further pulp refining studies focused on optimized fibre cement properties are recommended using addition rates based on the number of fibres per gram of pulp.

ACKNOWLEDGEMENTS

I would like to express my sincere thanks and appreciation to Paul Bicho, Wendy Tsai and the team at the Canfor Pulp Innovation laboratory for their support and assistance with the refining trials and pulp testing.

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