JACK PINE TMP: EARLYWOOD VERSUS LATEWOOD AND EFFECT OF REFINING TEMPERATURE

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ABSTRACT

Pressurized refining of jack pine early- and latewood at 120 and 160 °C was conducted to better understand the refining response of these two types of wood tissues under different refining conditions. We observed that, for a given freeness, earlywood consumed more energy than latewood and that they disintegrated differently during refining and gave dissimilar papermaking properties.

KEYWORDS

Pinus banksiana Lamb., thermomechanical pulping, earlywood, latewood, physical and optical properties

INTRODUCTION

The influence of earlywood (EW) and latewood (LW) on paper characteristics has long been recognized especially for paper made from chemical pulp [1-3]. This concern has also been lately acknowledged in mechanical pulping [4-8]. Recently, Law [4, 9] found that the long fibres in TMP are principally derived from the LW [10]. It is conceivable because when subjected to a compression load, the thin-walled EW fibre absorbs more energy and yields well in advance of the thick-walled counterpart [11]. The former ruptures in radial cell wall while the latter separates in inter-cellular mode. These mechanical responses lead to a total or partial disintegration of EW fibre under compression, meaning that this wood tissue can be fragmented in the screw-pressing stage when a large compression ratio is used. Plug-screw pressing, which involves various kinds of forces, further facilitates the destruction of the EW fibre during refining, generating short elements and fines in the final pulp. Meanwhile, the LW fibre, being mechanically more resistant, suffers lesser extent of structural disintegration, maintaining better its initial length.

To gain a better understanding on the response of EW and LW in thermomechanical pulping (TMP), we conducted TMP trials on these two types of chip. Jack pine (*Pinus banksiana* Lamb.) was used in the pilot trials for its high proportion of LW.

EXPERIMENTAL

Material

Logs of freshly fell jack pine (*Pinus banksiana* Lam.) were used. The sample trees were about 25-30 years old. The logs were first debarked manually and cut into disks of about 2.5 cm thick in longitudinal direction. Chips were prepared manually using a chisel to separate the earlywood and the latewood. The separation was based on the difference in color; the latewood in jack pine was relatively broad and much darker than the earlywood counterpart. The separation of earlywood from latewood permitted us to study the refining responses of the two types of wood within our global research framework. Due to the lengthy chip preparation it was necessary to air dry the chips for storage. However, they were rewetted prior to refining.

Refining

The early- and latewood chips were separately refined using our refining pilot plant (Metso CD 300). The pilot unit has a nominal capacity of 2 mt/day and is equipped with a rotor R3809BG and a stator R3803. Prior to refining, the chips were pre-steamed under atmospheric condition for 10 min and then screw-fed (compression ratio 2:1) into a digester where they were steamed at 120 and 160 °C for about 8 min. Pressurized refining was performed at that same temperature. The first-stage refining consistency was 22-25%. The primary pulp having a freeness of about

500 mL was further refined at lower consistency of 15-18% under atmospheric pressure using the same refiner plates to produce pulps of four freeness levels.

Fibre and Pulp Characterization

Pulp freeness and handsheet properties were determined following the appropriate PAPTAC standard methods while the fibre length was measured using a Fiber Quality Analyzer (OpTest Equipment, Canada).

RESULTS AND DISCUSSION

Refining Energy

Refining at 160 °C was much favourable than that at 120 °C in terms of freeness reduction, at a given energy consumption (Fig 1). This phenomenon suggests that the chip refining mechanism is much dependent on the pressurized conditions. At 160 °C the wood matrix is much softer than at 120 °C. Consequently, it is necessary to reduce the refiner plate clearance to achieve the desired freeness. The reduction in refiner plate gap results in greater fibre cutting, reducing fibre length.

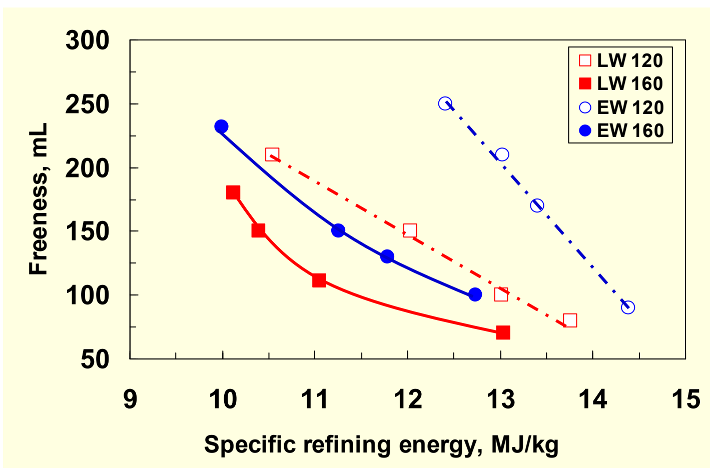

Fig. 1. Freeness vs. refining energy

Interestingly, the earlywood (EW) absorbed more energy, at a given level of freeness, when compared with the latewood (LW). This finding is in agreement with that reported [7]. This characteristic reveals the difference in responses to refining action between EW and LW. In contrast to the LW fibres, the EW counterpart might simply be fragmented without much fibrillation of the cell wall.

Characteristics of Fibre

Fibre fraction. The distribution of length fractions constitutes an important nature of mechanical pulps. It reflects the resistance of wood fibres to the mechanical forces exerting by the refiner plates. It also indicates the responses of fibres to different refining conditions such as temperature, plate gap and chemical treatments. The development of some fibre fractions is shown in Fig. 2.

The longest Bauer McNett fraction, R14, represents the intact fibres, separated or in bundles. The quantity of this fraction remaining in a mechanical pulp would indicate the extent of refining. Since the approximate EW-to-LW ratio in jack pine was 50/50, Fig. 2 shows that over 90% of the initial fibres were shortened as a result of refining, particularly for the EW fibres due to their comparatively thinner cell wall. The effect of fibre cutting aggravated with increasing refining energy (reduction in freeness). Interesting fact, refining at 160 °C promoted cutting because of additional plate gap reduction at this high temperature when compared to the refining at lower temperature such as 120 °C. The particular effect of fibre shortening in high temperature was also evidenced in other fractions such as R28 and R48, the data of which are not shown here for brevity.

While the R14 fraction represents the intact fibres remaining after refining, the short fibre fractions such as R100 and R200 correspond to the accumulated effect of fibre cutting induced by the refining action. Again, as seen in Fig. 2, refining at 160 °C promoted fibre cutting in comparison with the refining at 120 °C, and the EW suffered more physical destruction as compared to the LW. The fines, P200, consist of ray cells, flake-like outer layer of cell wall and fibrils resulted from the cutting and/or peeling effects of refiner plates. Quantitatively, refining at 160 °C generated more fines from LW, Fig. 5 shows. However, there was little difference between the LW and the EW when the refining was carried out at 120 °C.

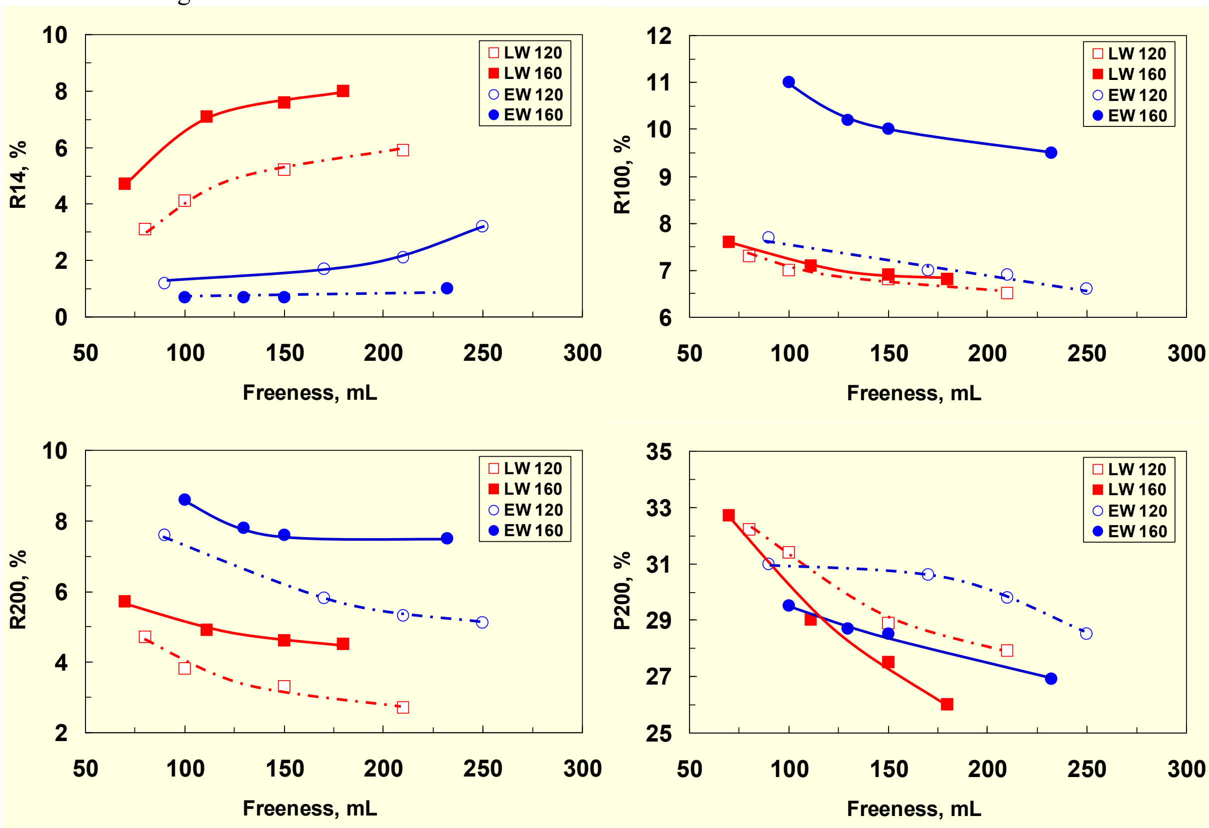

Fig. 2. Distribution of some fibre fractions vs. freeness

Fibre length. The adverse effect of high temperature (160 °C) refining on fibre dimension was also evidenced by lower length-weighted fibre length (Fig. 3). This is due to the reduced refiner plate gap used at 160 °C. The influence of high temperature refining was particularly significant with the EW. Due to their thin cell wall the EW fibres suffered greater loss in length as compared to the thick-walled counterpart.

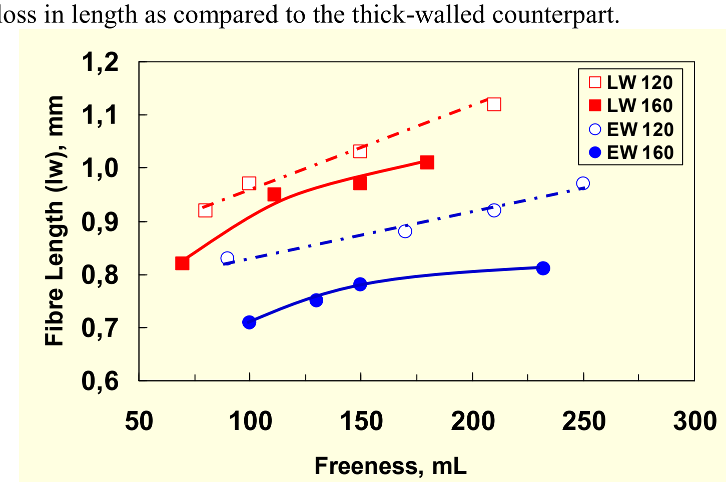

Fig. 3. Fibre length vs. freeness

Rejects. High temperature (160 °C) refining increased significantly the rejects of LW, but had no influence on that of EW (Fig. 4). Results from this study suggest that the rejects component in TMP might be principally attributed to the thick-wall LW fibres.

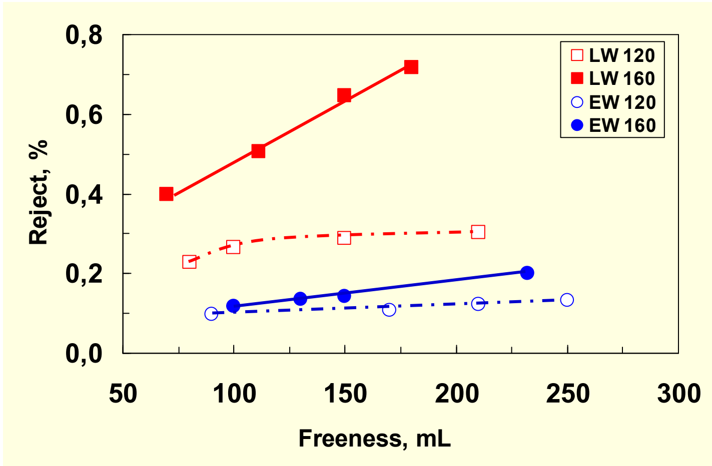

Fig. 4. Rejects vs. freeness

Characteristics of Handsheets

Density. As a result of increased fibre cutting with high temperature (160 °C) refining, the handsheet density of the resulting pulps was higher when compared to that of pulps produced at lower temperature (120 °C), Fig. 5 shows. Note that at a given freeness the EW fibres produced denser sheet in comparison with the LW counterpart, thanks to the thinner cell wall of the former.

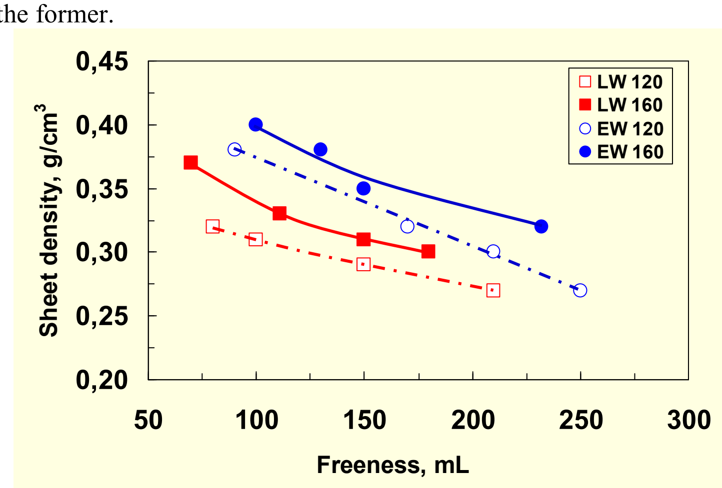

Fig. 5. Handsheet density vs. freeness

Porosity. With thick cell wall (increased stiffness) the LW fibres produced sheets having higher porosity when compared to those made from the EW fibres which has thinner cell wall (Fig. 6). However, the refining temperatures did not seem to have remarkable effect on the porosity of handsheet.

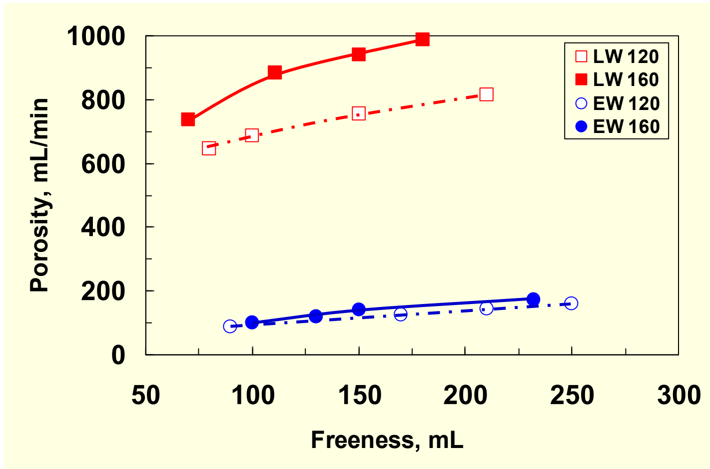

Fig. 6. Porosity vs. freeness

Roughness. Surface smoothness is an important property of printing paper and jack pine is known to produce sheet with high roughness due to its thick-walled fibres. As seen in Fig. 7, one advantage of high temperature (160 °C) refining was a lower surface roughness of handsheet. This is conceivable since refining at 160 °C increased fibre cutting, and as a consequence, increased sheet density, as discussed earlier (Fig. 5).

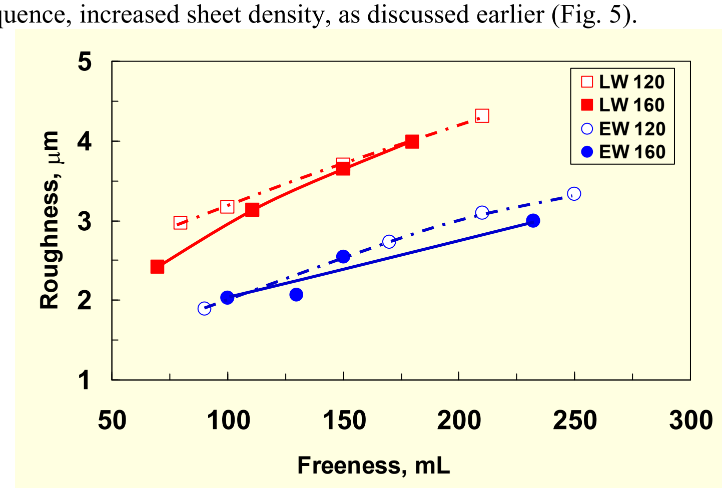

Fig. 9. Roughness vs. freeness

Tensile index. Fig. 8 shows that the influence of high temperature refining on tensile index of LW was not evident. However, it reduced noticeably the tensile strength of EW sheet, for a given freeness. As discussed earlier, at a given freeness, the high temperature refining required less energy than the low temperature refining (120 °C). The particularly good tensile index of EW pulps produced at 120 °C was due to the high energy consumption of EW fibres (Fig. 1). Similar observation was also noted for burst index which is not shown for conciseness.

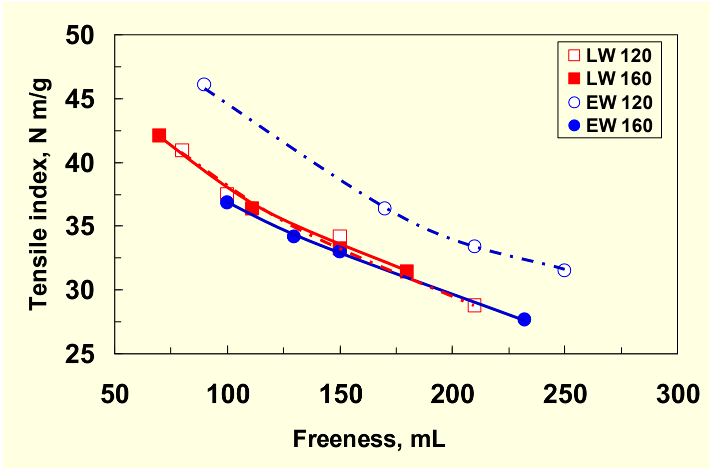

Fig. 8. Tensile index vs. freeness

Tear index. The fall in tear index due to high temperature refining was particularly notable for the thin-walled EW fibres which suffered more severe shortening in comparison to the thick-walled LW counterpart (Fig. 9). The high temperature effect was attributable to the fact that the refiner plate clearance has to be reduced by about half of that used at lower temperature to cope with the increased fibre softening effect (increased fibre flexibility) which decreases the fibre-to-plate friction.

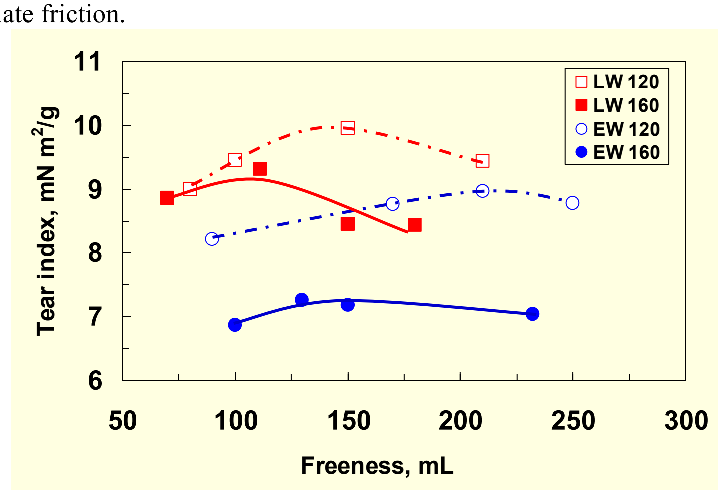

Fig. 9. Tear index vs. freeness

Optical properties. The most substantial detrimental effect of high temperature refining was, perhaps, the remarkable darkening effect, resulting in a significant drop in brightness (Fig. 10). The adverse effect of high temperature on brightness might be minimized through process optimization. As a consequence of reduced brightness the sheet opacity (Fig. 11) increased considerably when the refining was conducted at 160 °C. Additionally, the sheets made from the EW fibres showed noticeable higher opacity than those prepared from the LW fibres, which is due to the fact that the former had higher light scattering coefficient than the latter, Fig. 12 shows.

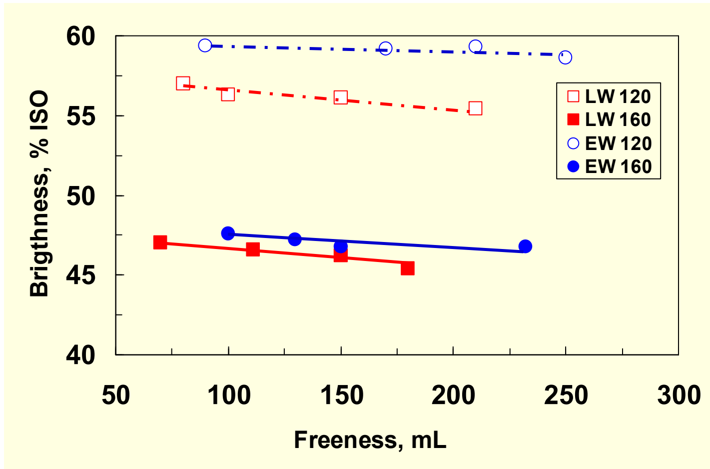

Fig. 10. Brightness vs. freeness

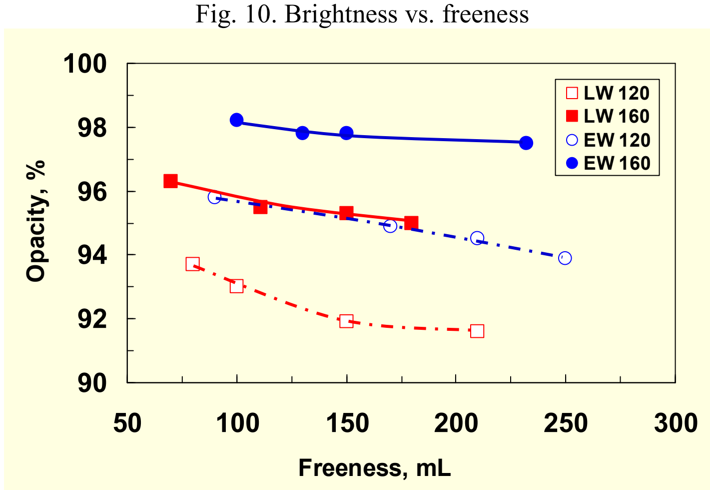

Fig. 11. Sheet opacity vs. freeness

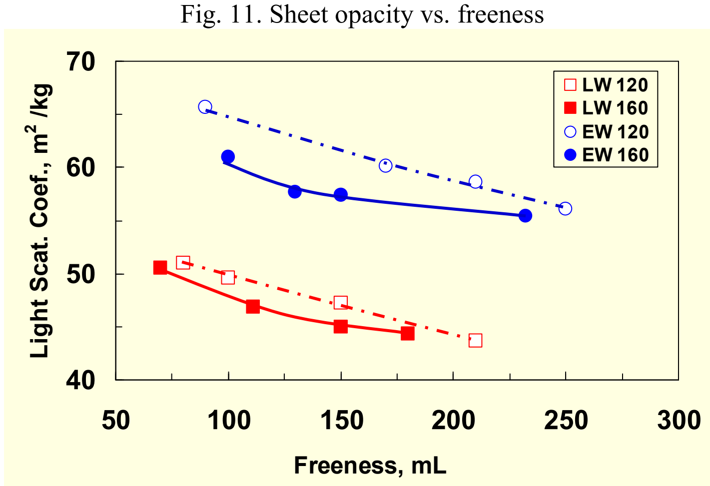

Fig. 12. Light scattering coefficient vs. freeness

CONCLUSION

The principal findings of this study include:

- Earlywood and latewood of jack pine behave dissimilarly in thermomechanical pulping; the former absorbs more refining energy, for a given freeness, and breaks down more easily in comparison with the latter.

- Significant saving in energy requirement can be achieved when the refining temperature increases from 120 °C to 160 °C, at a given freeness.
- High temperature refining (160 °C) produces more rejects from latewood but has little influence on that from earlywood.
- For a given freeness, the high temperature refining has no significance effect on tensile strength of latewood fibres but considerably reduces that for earlywood handsheets.
- Refining at 160 °C has important adverse influence on tear index, particularly for the earlywood fibres.
- High temperature refining decreases handsheet roughness due to more severe fibre shortening. It also reduces somewhat the light scattering coefficient of paper.
- On the negative note, the high temperature refining reduces sharply the pulp brightness.

ACKNOWLEDGEMENTS

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Jack Pine Tmp: Earlywood versus Latewood and Effect of Refining Temperature

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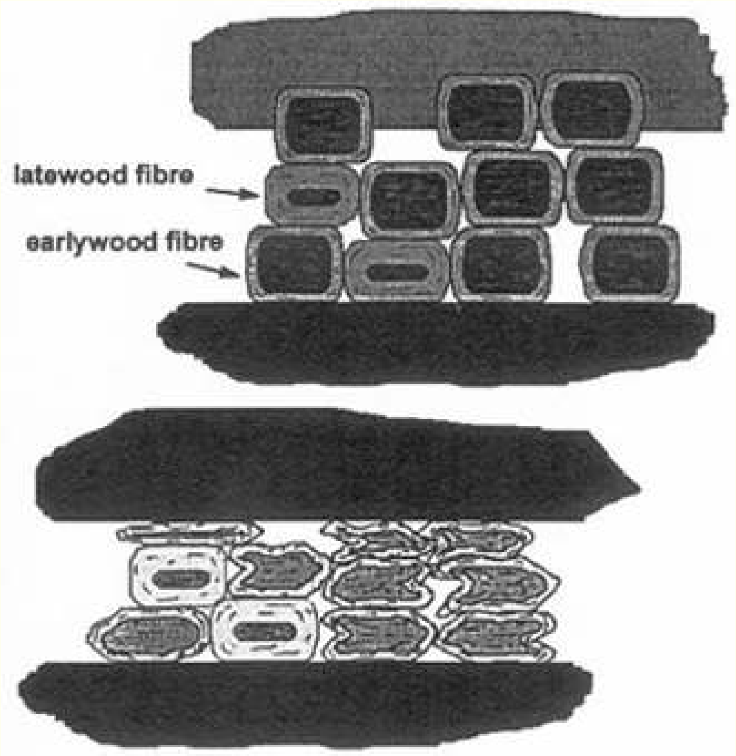
Introduction

Earlywood and latewood are different in terms of:

- **Width**
- **Cell wall thickness**
- **Lumen diameter**



The differences affect:

- **Compressibility of fibre**
- **Fibre development**

Introduction

LW percentage in selected Canadian softwood

Species	LW % (vol)	Basic density, kg/m^3	References
Black spruce	20	400	Ladell, J.L., 1971
White spruce	25	350	Szanyi, L., and Sugden E.A.N., 1967
Western larch	39	530	
Douglas fir	45	460	

Introduction
Morphology of jack pine fibres

	Earlywood	Latewood
Bulk density, g/cm^3	0.298	0.485
Mass, %	40	60
Length, mm	3.34	3.55
Coarseness, mg/m	0.168	0.195
Wall thickness, µm	2.12	4.75
Outer perimeter, µm	130	105
Lumen area, μm^2	400	260
Cell wall area, μm^2	240	350

Introduction

- **Previous research works show:**
  - **Earlywood requires more energy (*Murton, 2001*)**
  - **Earlywood fibres, being more fragile, rupture and break up into tiny fragments**
  - **while latewood fibres remain more intact (*Law, 2005*)**

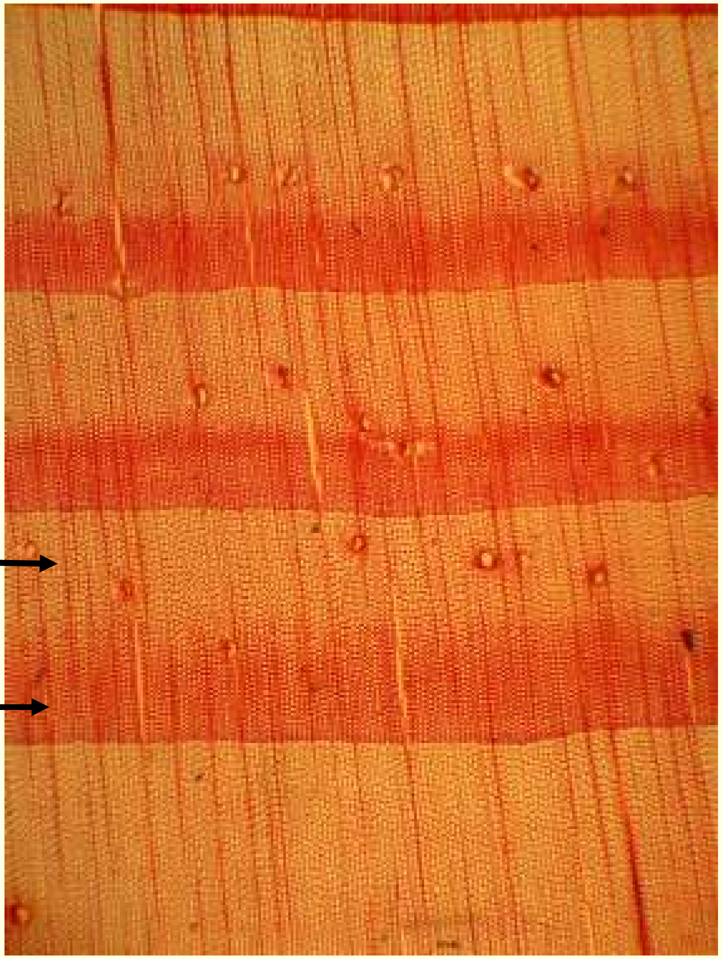
  ⇨ **Long fibre fraction of Bauer McNett**
  - **Long fibre fraction has poor bonding potential (*Law 2004*)**

Objectives

- **To gain a deeper insight into the refining response of early- and latewood fibres**
- **To examine the changes in fibre properties during TMP refining of Jack Pine**
  - **Particular focus on Bauer McNett fractions**
- **To have a better understanding on the mechanism of defibration and development of early- and latewood fibres.**

Material and method

- **Jack Pine logs, 30 years old, cut in disk of 2.5 cm thick**
- **Manual separation of earlywood and latewood using a chisel**

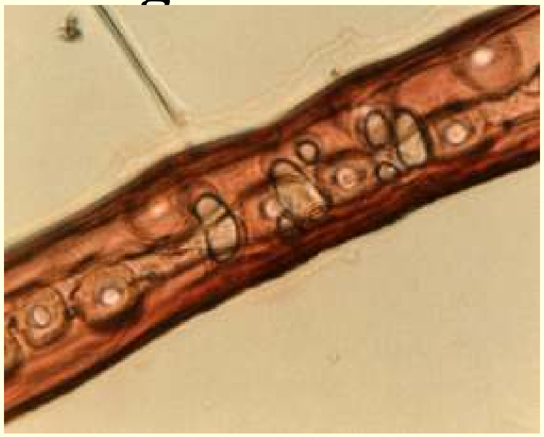


Earlywood, 36,3% in mass

Latewood, 63,7% in mass

Material and method

- TMP refining using a Metso CD300 Pilot refiner
  - 1^{st} stage at 120 ^{o}C, CSF 500 mL
  - 2^{nd} stage atmospheric, CSF from 250 - 80 mL
- Pulp analyses
  - Fibre length and coarseness (FQA)
  - Fiber wall thickness (TECHPAP analyzer)
  - Optical and physical properties using PAPTAC standard methods.



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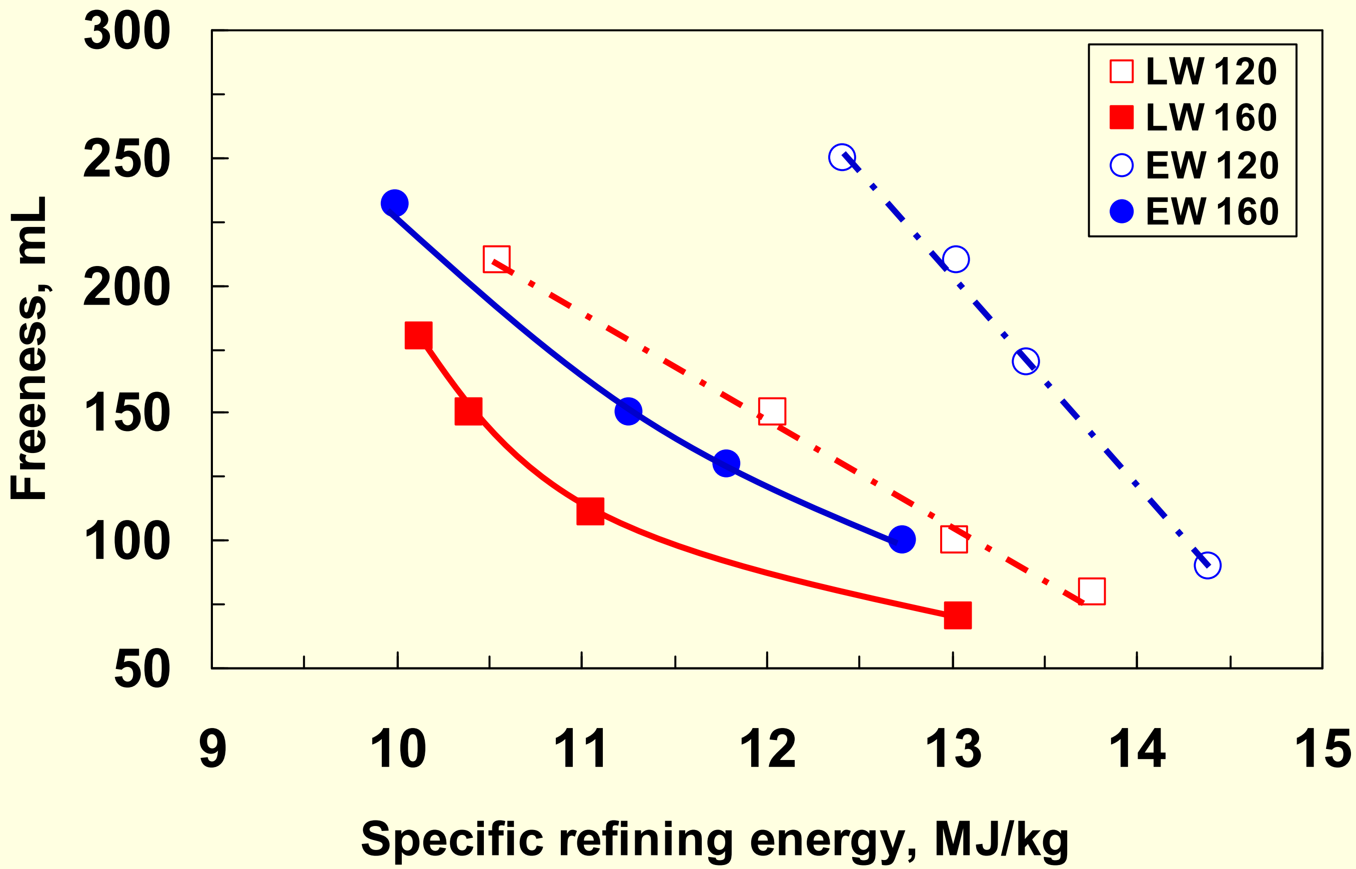

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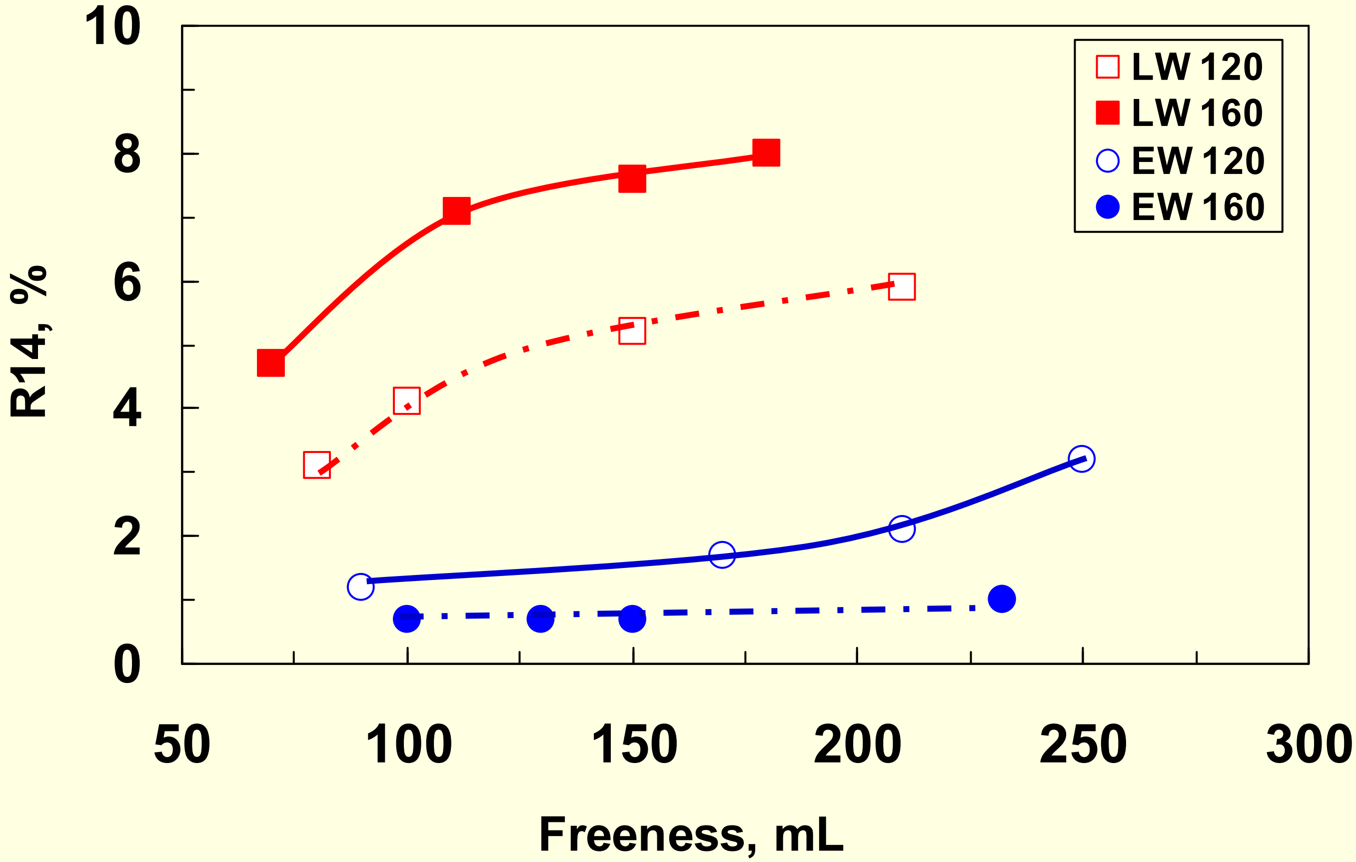

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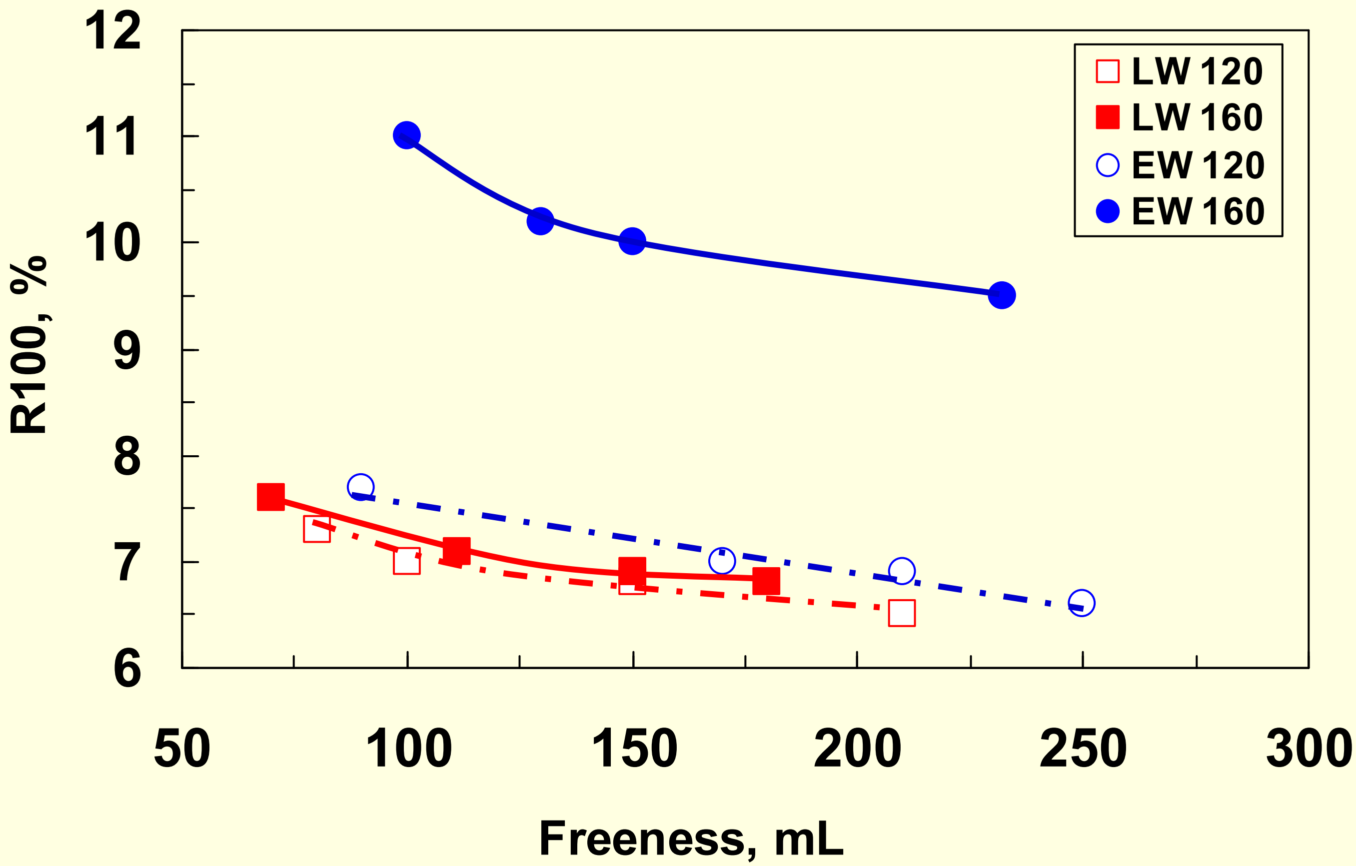

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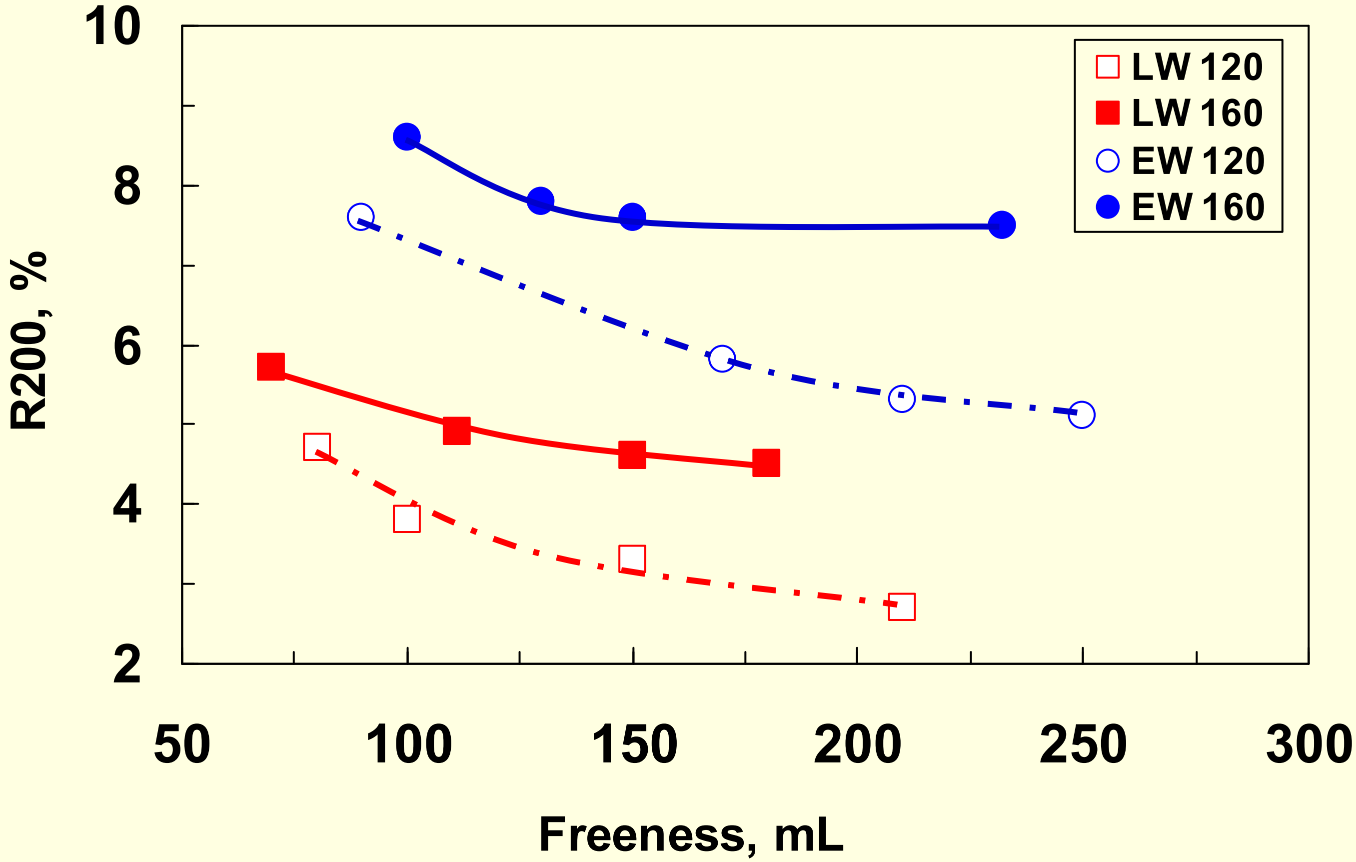

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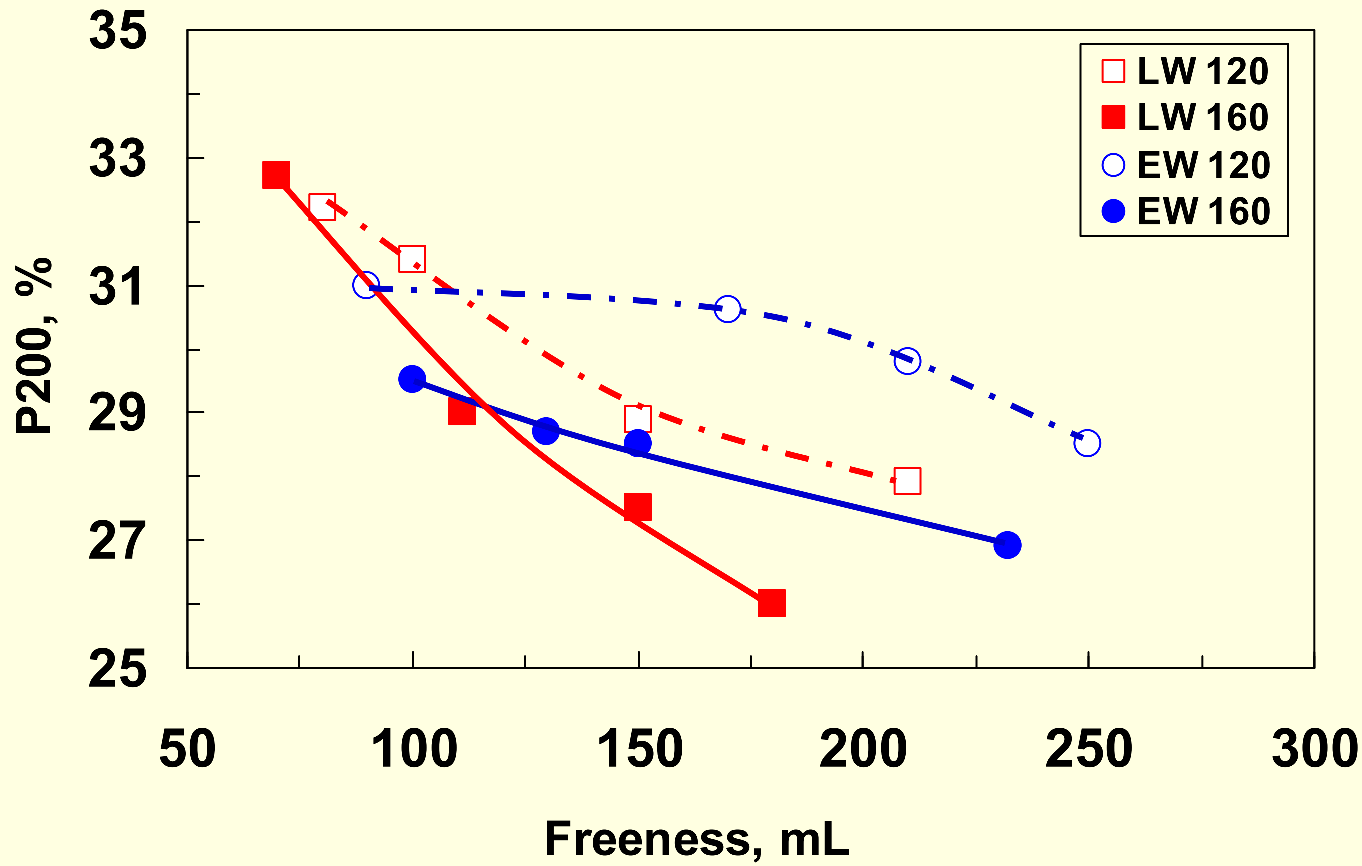

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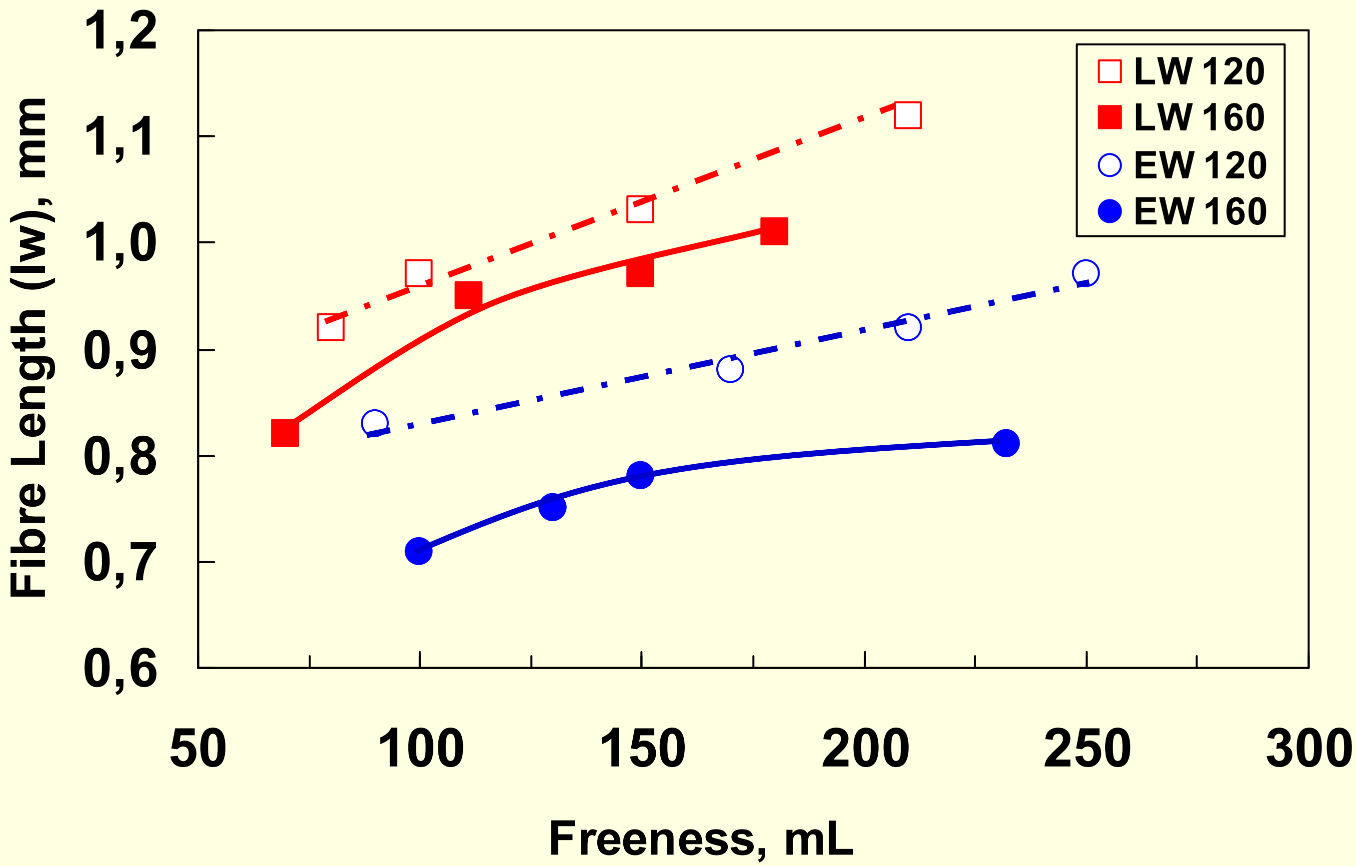

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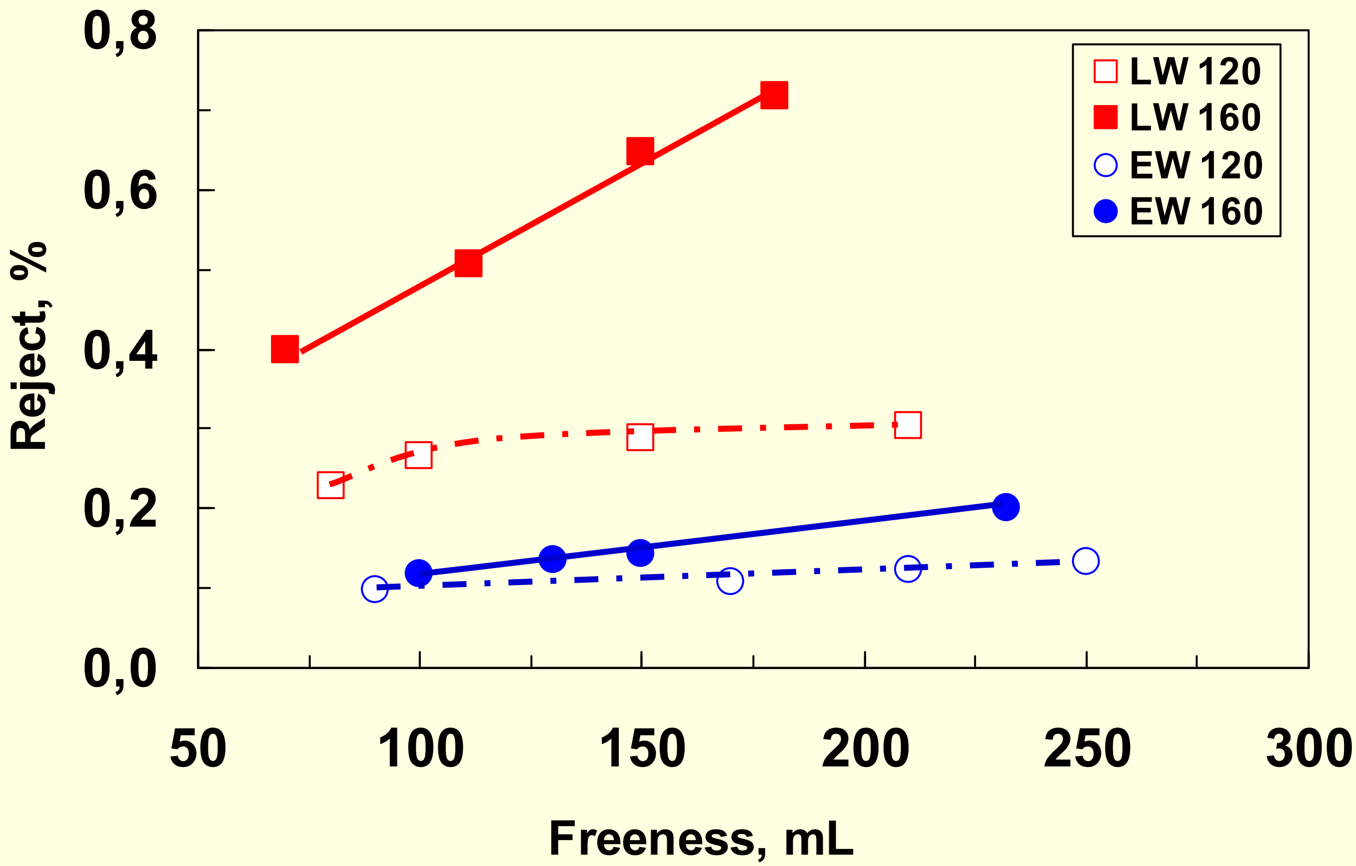

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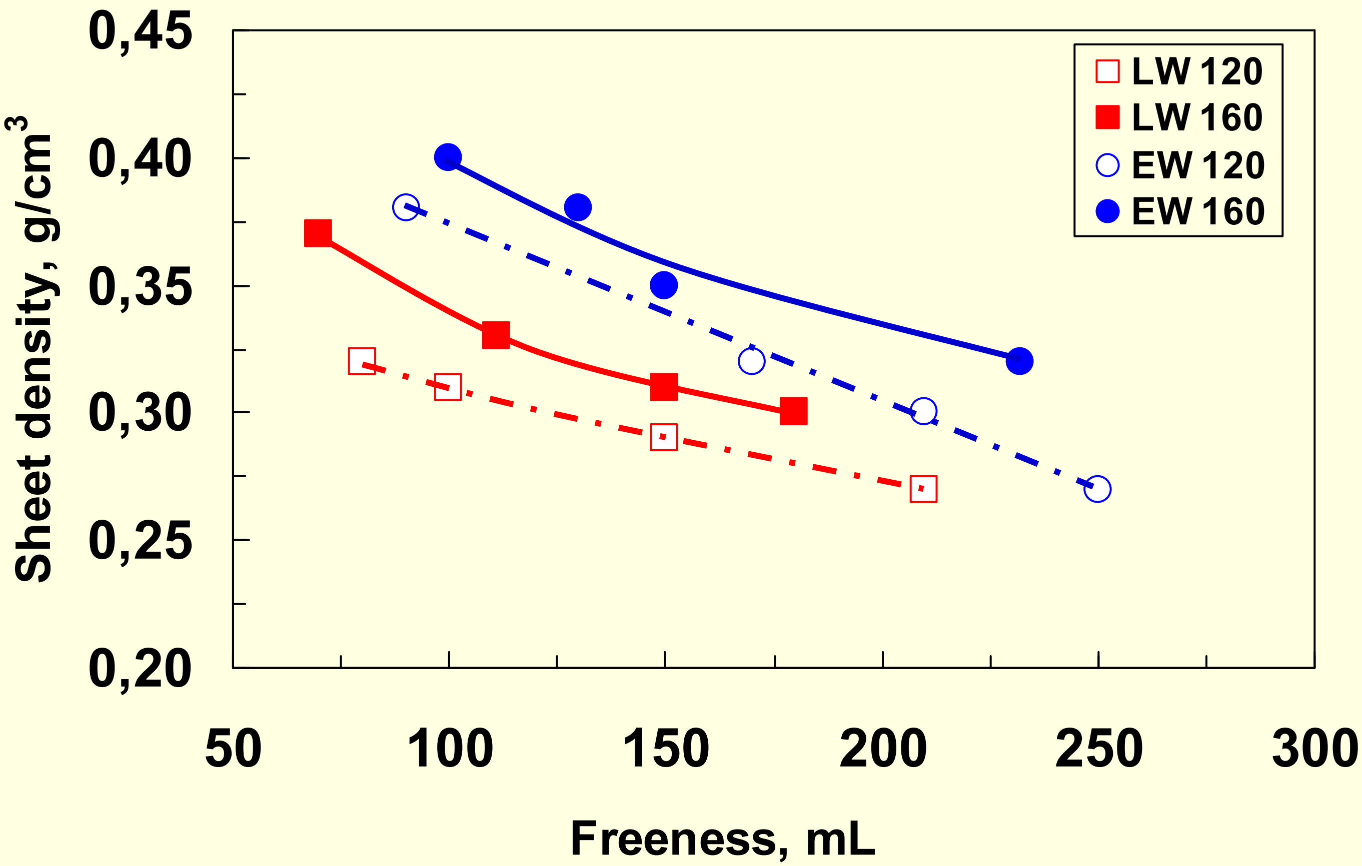

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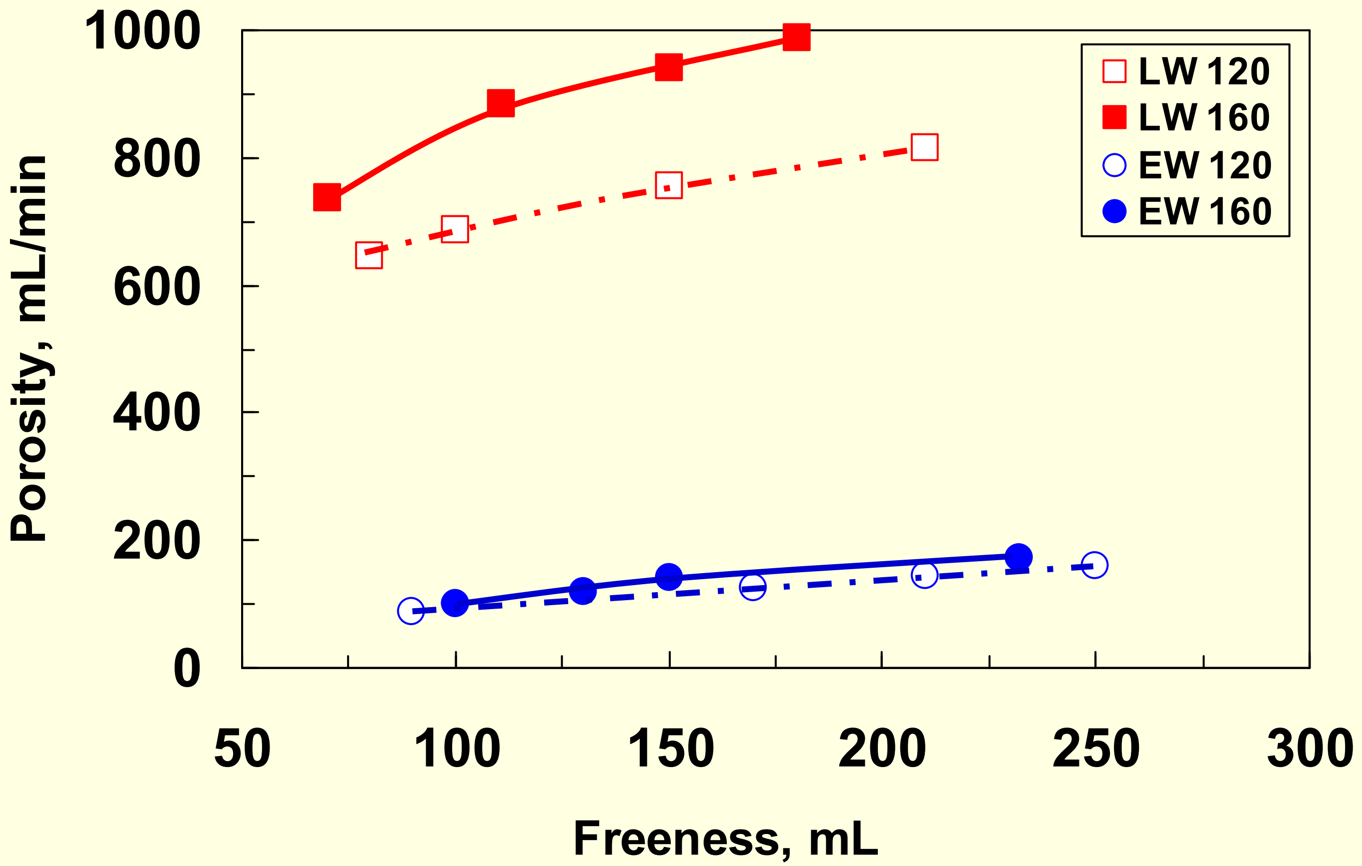

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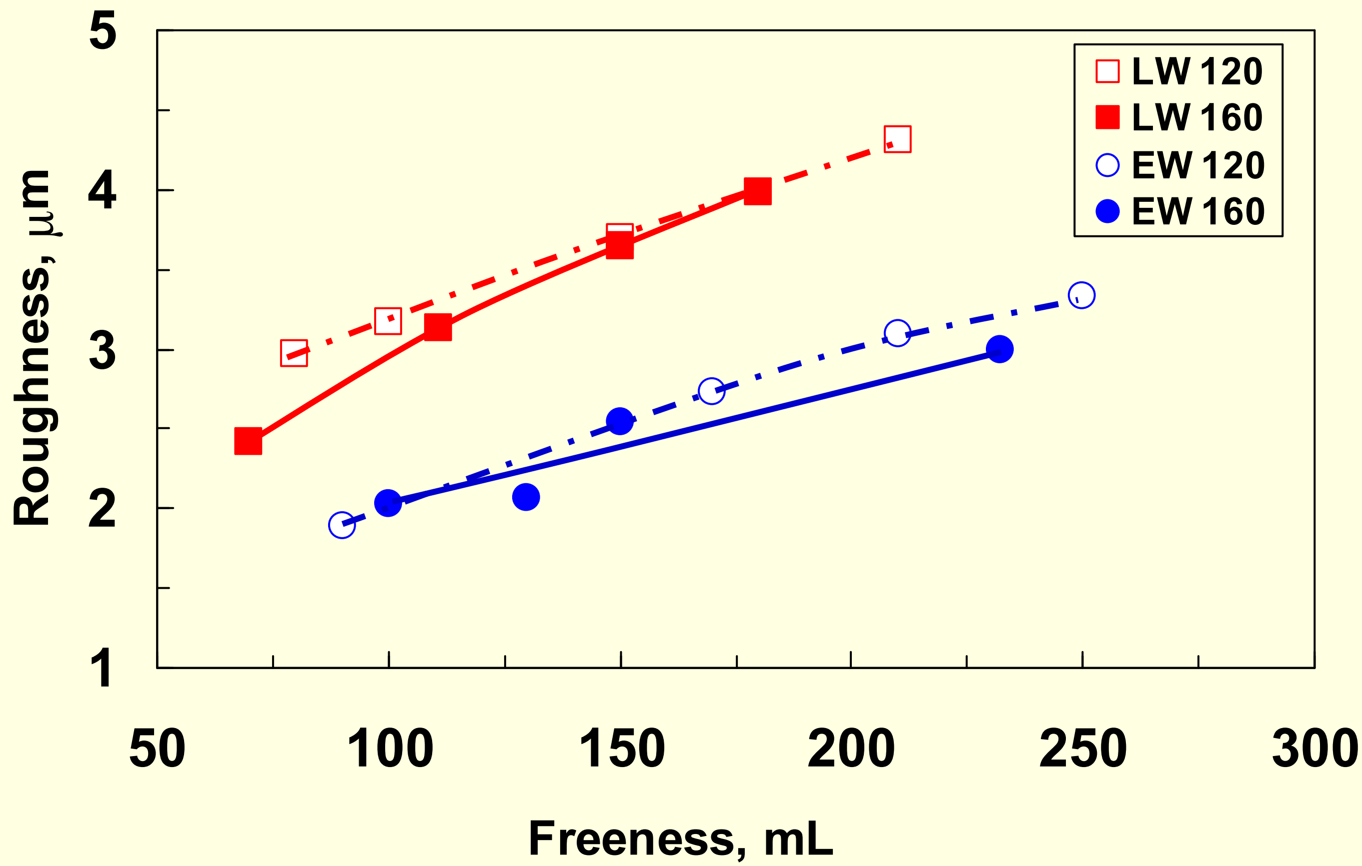

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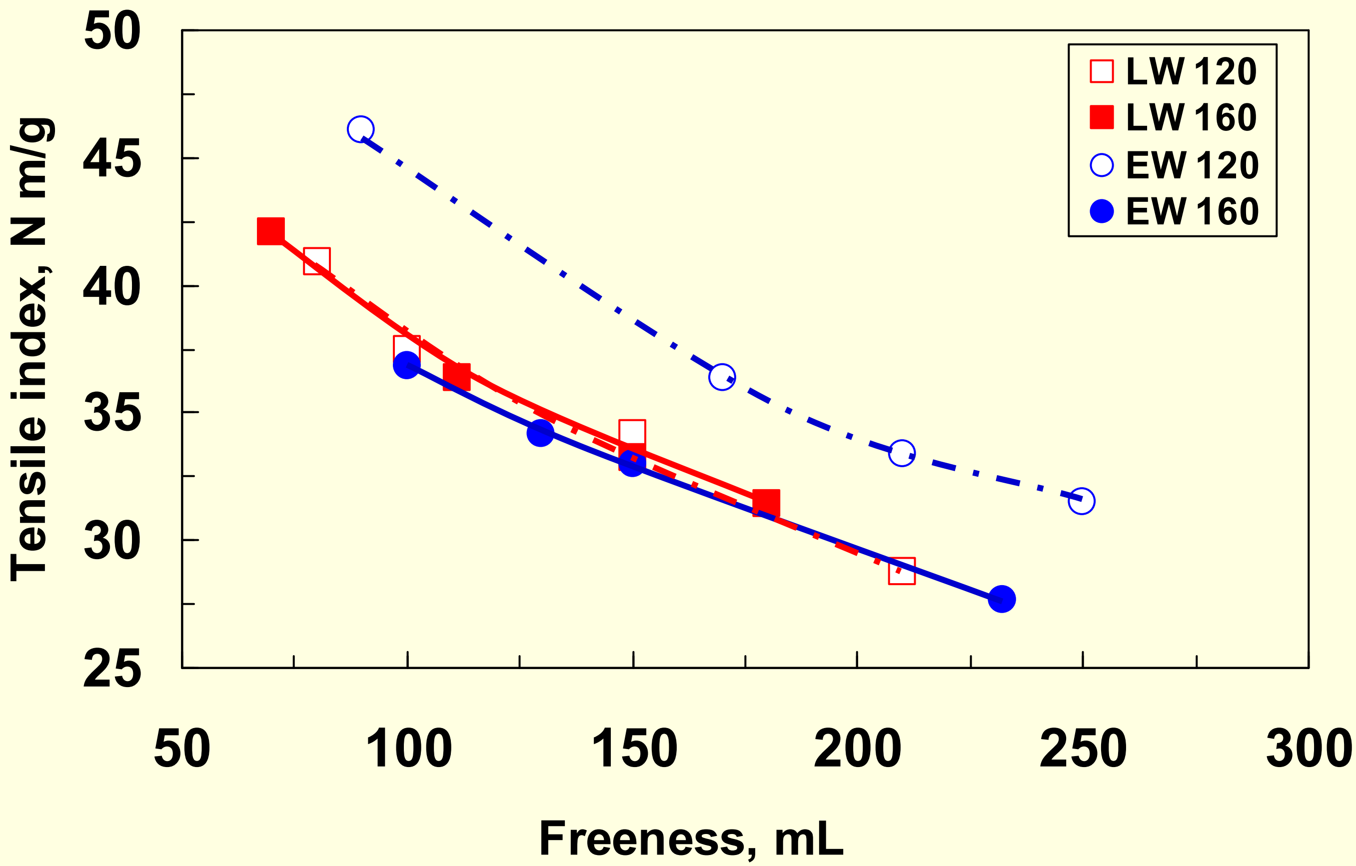

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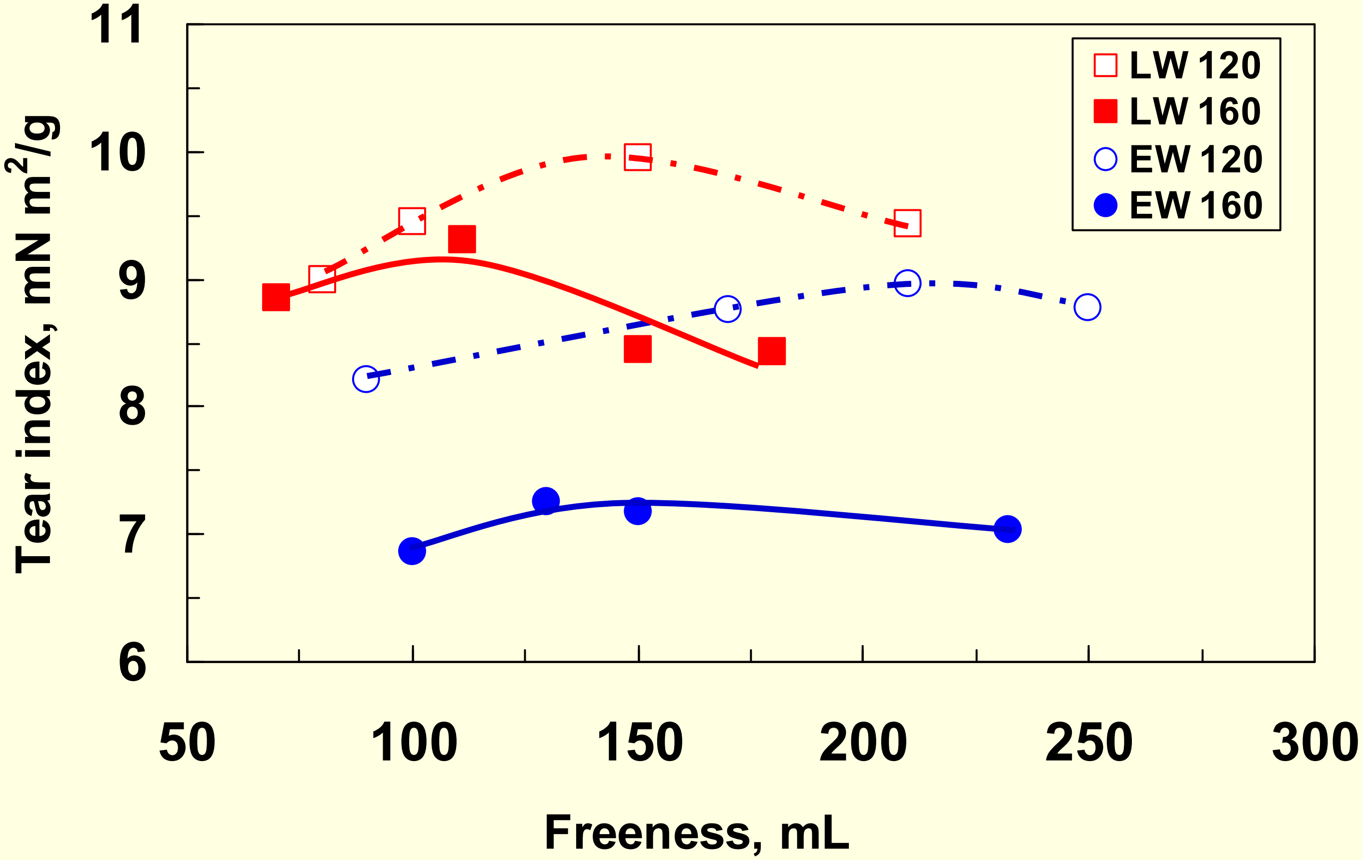

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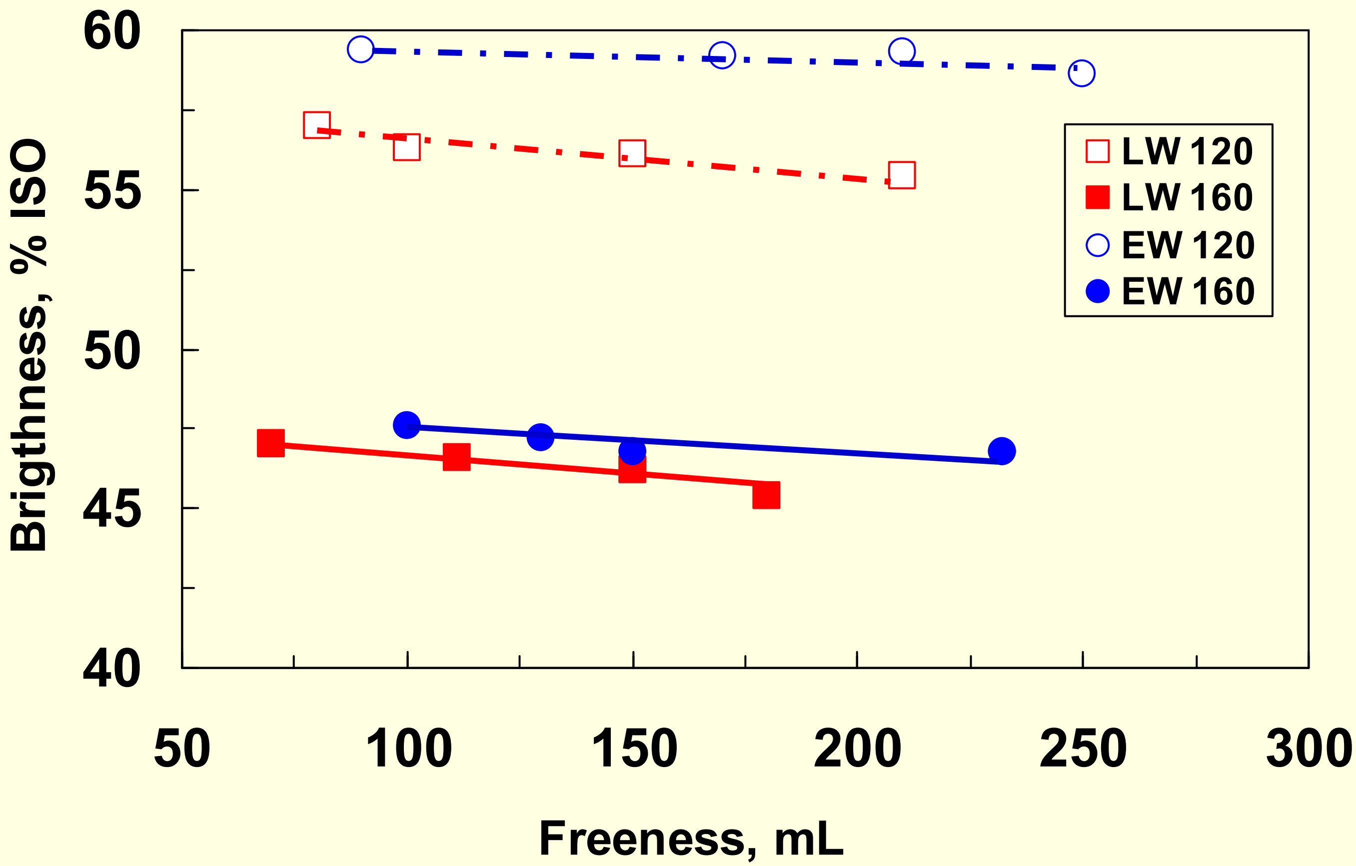

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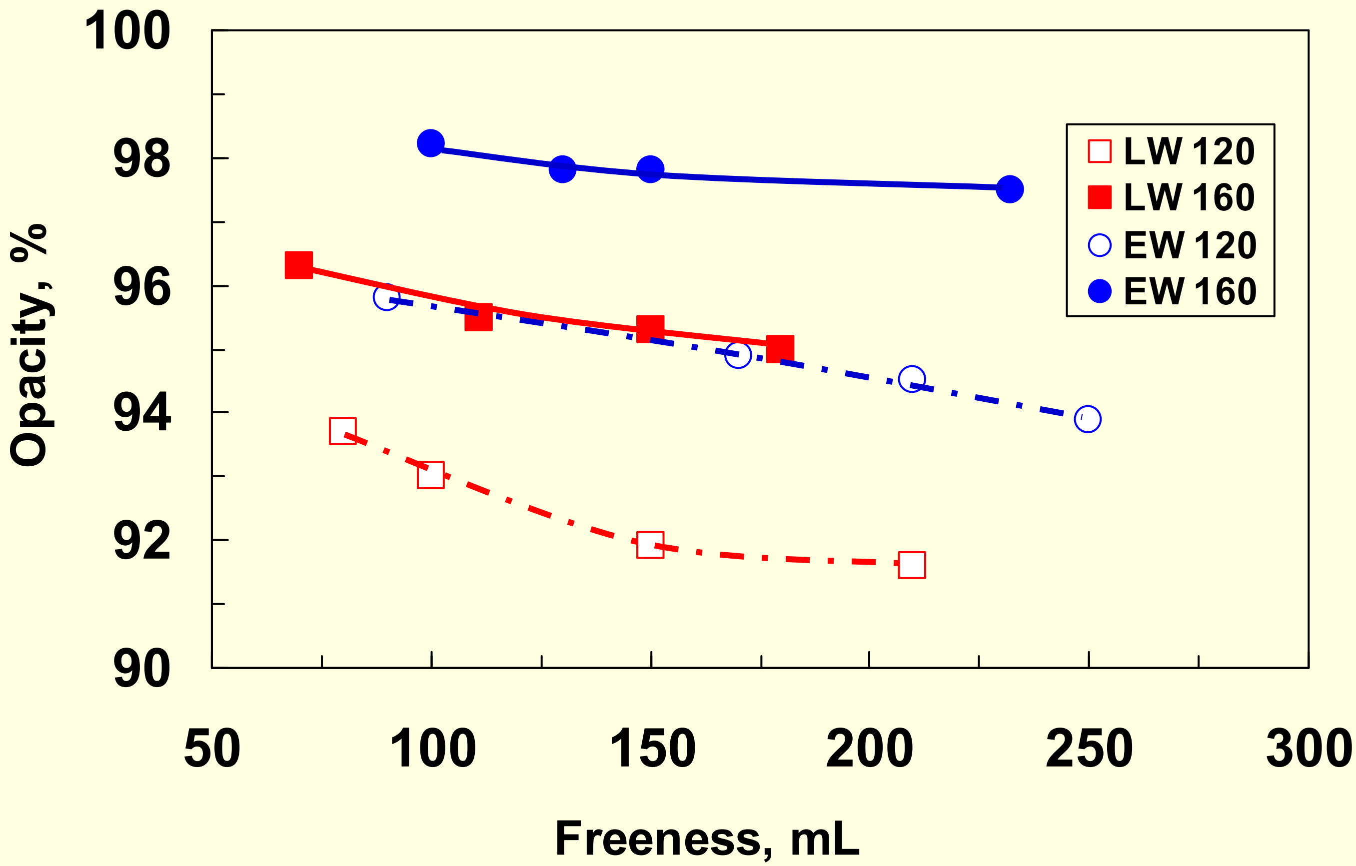

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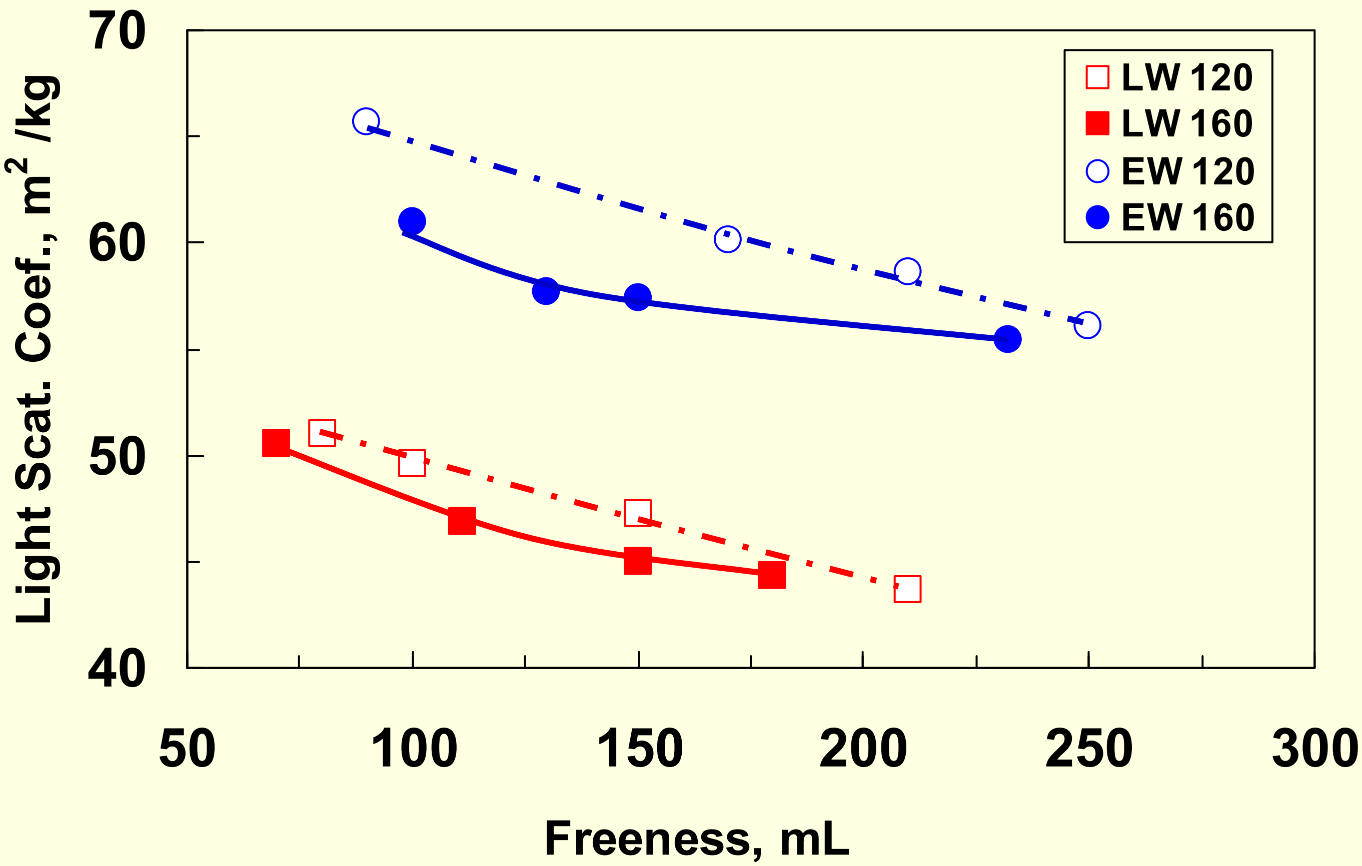

Conclusions

	Earlywood	Latewood
Refining energy	+	
Higher rejects		+
Average fibre length		+
Cell wall thickness reduction		+
SSV of fines (P200)		+

Conclusions

	Earlywood	Latewood
Tensile index		+
		(up to 13.3% MJ/kg
	+	
	(at CSF 100 mL)	
Tear index		+
Spec. light scatt. Coeff.	+	
Bauer McNett fractions:		
Sheet density	+	
Tensile and tear indices	+	
Light scattering coefficient	+	

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