The Effect of Extractives on the Disruptive Shear Stress in Pine Thermomechanical Pulps

Mirja Illikainen*, Esko Härkönen**, Jouko Niinimäki*
* Fibre and Particle Engineering Laboratory, P.O.Box. 4300, FIN-90014 University of Oulu, Finland
** UPM-Kymmene, R & D, FIN-53200 Lappeenranta, Finland

ABSTRACT

The effect of extractives on the disruptive shear stress in pine thermomechanical pulps was studied using the Equipment of shear and compression. Compressibility and the disruptive shear stress in first thinning pine and sawmill pine thermomechanical pulps were studied at a temperature of 120 °C. Additional experiments were done using the pulp from which extractives were removed by acetone extraction. The result of the study was that removal of extractives does not change the compressibility or disruptive shear stress in pulp.

INTRODUCTION

High quality raw material is required in thermomechanical pulp (TMP) refining. In practice, only spruce is used in Northern countries. There is growing interest in using the cheaper raw material, Scots Pine, in TMP refining as well. The problem with using pine is that pine requires much – as much as 30% – more energy than spruce to achieve the same freeness level, and the strength properties of pine pulp are inferior to spruce pulp /1,2/.

The reason for the different refining properties of these two different softwood species is not known. There are not many publications about the refining of Scots Pine. Reme /3/ has compared spruce and pine fibres and suggested that the reason for the higher energy consumption of pine could be that redistribution of extractives at the fibre surface in refining could reduce friction in the refining. Heum /4/ has listed also other proposed hypotheses for the inferior refining properties of Scots Pine: higher cell wall thickness of pine, higher microfibrill angle and other fibre differences.

In this paper the effect of extractives on disruptive shear stress in pulp pad has been studied using the Equipment of shear and compression. The disruptive shear stress in compressed pine pulps was measured as a function of compressive pressure and the volume fraction of pulp. Two pine pulps with different extractive contents were used in the experiments: thermomechanical pulps from first thinning pine and sawmill pine chips. Experiments were also done using the pulp from which extractives were removed by acetone extraction.

EQUIPMENT OF SHEAR AND COMPRESSION

The Equipment of shear and compression (ESCO) is presented in Fig 1. The main parts of the ESCO are the cylindrical vessel with a diameter of 152 mm, the pneumatic press and the rotating bottom of the vessel. The device is connected to the steam line. High-pressure steam is used to heat up the pulp. The temperature of the steam is controlled using a pressure-reducing valve. Temperatures up to 180 degrees are possible. The ESCO is connected to the computer that is used for operating the equipment. All the measured data is collected and stored in the computer: temperatures inside the cylinder, piston position, compressive force and torque. The measuring frequency of 141/s is used.

The main operational principles of the ESCO are presented in Fig 2. 1. The pulp is put into the cylinder between perforated plates and then the bottom and the top of the cylinder are bolted. 2. Pulp is heated using steam so that steam flows through the pulp pad and is also present through the experiment in order to keep temperature at its target value. At the bottom of the vessel there is a valve for condensed water. 3. Pulp is compressed using the piston and the pneumatic press. During compression the upper and lower side of the cylinder are connected for pressure balancing. Compressive pressures for fibres from 1 to 8 bars can be used. The distance between the tops of the needles, as well as the compressive pressure, are measured during the experiment. After compression the bottom plate is rotated and the compressed pulp pad is disrupted. The motor is connected to the axis of the bottom plate and it is used for rotating the bottom. The torque required is measured. Rotational speeds from 5 to 84 rpm can be used.

ESCO can be assembled using different surfaces on the bottom and the piston plates. For studying shearing properties, the bottom and the piston of the cylinder are completed with needles (Fig 3). Fig 4 illustrates an
example of the output data of the shearing experiment. The top of the torque curve is used for calculating the disruptive shear stress.

Fig 1. Shear and compression equipment.

Fig 2 Main operational principles of the equipment.
MATERIALS AND METHODS

Materials

Two different Scots Pine thermomechanical pulps were used in these experiments: one produced from first thinning pine and the other from sawmill pine chips. The pulps were produced by using a 20-inch pilot refiner. Freeness levels, average fibre lengths and specific energy consumptions are presented in Table 1.

Table 1. Specific energy consumption and freeness levels of TMP pulps used in experiments.

<table>
<thead>
<tr>
<th>wood species</th>
<th>refining stages</th>
<th>SEC (MWh/t)</th>
<th>Total SEC (MWh/t) (1st, 2nd, 3rd stages)</th>
<th>CSF (ml)</th>
<th>Fibre length</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sawmill pine</td>
<td>2</td>
<td>0.51</td>
<td>1.86</td>
<td>340</td>
<td>2.1</td>
</tr>
<tr>
<td>Thinning pine</td>
<td>2</td>
<td>0.76</td>
<td>1.92</td>
<td>298</td>
<td>1.7</td>
</tr>
</tbody>
</table>
Methods

The ESCO was used to study the disruptive shear stress in compressed pulp pad. The disruptive shear stress in compressed pulp pad was measured as a function of the compressive pressure or volume fraction of pulp, at a temperature of 120 °C. The amount of pulp in the experiments ranged from 75 to 130 g absolutely dry pulp depending on the pressure used. The amount of pulp was chosen so that the distance between the needles after compression was about 5 mm in all experiments. Pressures from 1 to 4 bars were used. The average fibre pressure in the refiner disc gap has been reported to be below 1 bar /5/. Higher pressures were used as there is no reason to believe that force is evenly distributed in the disc gap.

The pulp was put into a cylinder in dry content of about 15%. A heating time of 15 minutes was used. After the heating the pulp was compressed using the certain compressive pressure. The compressed pulp pad was disrupted and torque needed was measured. The rotational speed of the bottom of the cylinder was 8.4 rpm.

Additional experiments were also done using pulp in which extractives (acetone dissolved substances) were removed. Experiments were done similarly as described above, but using the acetone-treated pulps.

Acetone Extraction

Acetone extraction was done by using the modified version of standard SCAN-CM:49. 100g of absolutely dry pulp was loaded into Soxhlet-colon and extracted using 1500g of acetone. An extraction time of four hours was used. The amount of extraction circulations was not determined. For both pulps (sawmill and first thinning pine) five corresponding extractions were carried out to achieve the needed amount of extracted pulps for the experiments. The amount of removed components was determined after one extraction for both pulps. The extraction solution was evaporated at a temperature of 80 °C and the remaining material was weighted.

Equations

Equation 1 presents the definition of the volume fraction of pulp. The density of the fibre cell wall was used for calculating the volume of fibre solid material, which is then compared to the total volume of pulp.

\[
\varepsilon = \frac{V_{fibre \ material}}{V_{total \ volume}} = \frac{m}{\rho_{fibre \ wall} \ V_{total \ volume}} \tag{1}
\]

where

- \( \varepsilon \) is the volume fraction of pulp
- \( V \) is the volume of fibre cell wall
- \( V \) is the total volume of pulp
- \( m \) is the mass of absolutely dry pulp (kg)
- \( \rho \) is the density of fibre wall (1500 kg/m3)

Compressed pulp pad was disrupted by rotating the bottom of the vessel. It was assumed that pulp pad behaves like an elastic material before disruption; therefore Hooke’s law /6/ was used to describe its behaviour. The compressed pulp pad was considered as a rigid circular shaft. The shear stress in the rigid shaft varies linearly with the distance from the axis of the shaft (Fig. 5) /6/. The disruption starts when the highest value of shear stress is achieved. The maximum shear stress in pulp pad as a function of torque is presented in Equation 2 /6/ and it is here referred as a disruptive shear stress. After disruption shearing surfaces slide against each other and shear stress is then likely to be more uniformly distributed.
\[ \tau_{\text{max}} = \frac{T \cdot r_{\text{max}}}{J} \]  

(2)

where \( \tau_{\text{max}} \) is the disruptive shear stress, \( T \) is the torque, \( r_{\text{max}} \) is the radius of the cylinder, and \( J \) is the polar moment of inertia, 

\[ J = \frac{\pi \cdot r_{\text{max}}^4}{2} \]

**Fig 5. Shear stress distribution in a rigid circular shaft /6/.

**RESULTS**

The amount of extractives (acetone dissolved substances) was determined in connection with the acetone extraction. Table 2 shows the amount of extractives for first thinning pine and sawmill pine pulps.

Table 2. Extractive content of pulps determined by acetone extraction.

<table>
<thead>
<tr>
<th>pulp</th>
<th>Acetone dissolved substances [%]</th>
</tr>
</thead>
<tbody>
<tr>
<td>thinning pine</td>
<td>2.50</td>
</tr>
<tr>
<td>sawmill pine</td>
<td>2.06</td>
</tr>
</tbody>
</table>

The distance between the tops of the needles was measured during the experiments and the volume fraction of pulp was calculated. Fig 6 presents the compressibility of pulps: the volume fraction of pulp as a function of the compressive pressure. Sawmill pine and first thinning pine pulps were equally compressible, as well as pulps from which extractives were removed.
Fig. 6. Compressibility of first thinning pine and sawmill pine TMP pulps.

After compression the disruptive shear stress was measured. The disruptive shear stress as a function of compressive pressure and volume fraction of pulp is presented in Fig 7 and 8 respectively. Disruptive shear stress seems to be a linear function of compressive pressure. No differences between first thinning pine and sawmill pine or between extracted and non-extracted pulps can be seen.

Fig. 7. Disruptive shear stress as a function of compressive pressure.
DISCUSSION

In this study extractives were removed by acetone extraction. Acetone extraction is a widely used method to remove extractives from pulp. Acetone extraction effectively removes common wood resin components. The problem when using acetone is that it also extracts some hydrophilic components such as simple sugars and phenyl glycosides /7/. Acetone extraction is, however, a simple method with a cheap and harmless solvent and was thus chosen to this study. During the extraction the extractive content of sawmill and first thinning pine pulps was determined. The extractive content of first thinning pine pulp was higher (2.5 %) compared to sawmill pine pulp (2 %). That is because the first thinning wood is juvenile wood that contains a higher amount of extractive-rich knot- and reaction wood compared to mature wood /8/

The compressibility of extracted and non-extracted pine pulps was determined using the ESCO. As can be seen in Fig 5 there was no differences in compressibility between these different pine pulps. The removal of extractives or change in fibre length (see Table 1) did not affect the compressibility of pine pulps. Fig 7 and 8 illustrate the disruptive shear stress in these pulps as a function of the compressive pressure or volume fraction of pulp. No differences between pine and spruce pulp can be seen. The extractives cannot thus be a reason for the higher energy consumption of the refining of pine compared it to the refining of spruce.

CONCLUSIONS

The amount of extractives did not affect the disruptive shear stress in pine pulps. That indicates that extractives do not change the friction during the refining and that extractives are not the reason for the different refining properties of spruce and pine pulps.

ACKNOWLEDGEMENT

The authors would like to thank laboratorian Jarno Karvonen from University of Oulu for his assistance in laboratory work. UPM-Kymmene, Metso Paper and Finnish Ministry of Education are gratefully acknowledged for financing this research.

References


The Effect of Extractives on Disruptive Shear Stress in Pine TMP Pulps

Mirja Illikainen, Esko Härkönen, Jouko Niinimäki
• Equipment of Shear and Compression
  • Why this kind of equipment?
  • How it works?

• The effect of extractives on shearing behavior of pine TMP pulps
  • Why? How?
  • What can we learn?
• Electrical energy consumption of TMP refining is extremely high
  Although theoretically only small amount of energy is needed to separate fibres and to produce new fibre surfaces

• Mechanism-study is needed
• Studying refining phenomena inside the refiner is difficult due to harsh conditions there.

• **Equipment of shear and compression** is our tool to attain new valuable information about mechanisms of refining.
Amount of pulp in a refiner disc gap is so high that fibres are compressed between rotor and stator

(Härkönen & Tienvieri 2001)
Shear stress mechanisms in a disc gap

(Härkönen & Tienvieri 2001)
Important factors determining refining phenomena:

- Compressibility of fibres
- Volume fraction of fibres in a refiner disc gap
- Friction between pulp and segment surface
- Friction inside the pulp pad
Equipment of shear and Compression
ESCO
Equipment of shear and Compression ESCO

Operational conditions:
- Temperatures 100 ... 170°C
- Compressive pressures 1 ... 8 bars
- Torques ... 500 Nm
- Rotational speeds ~ 8 ... 84 rpm

Measurements:
- Temperature
- Piston position
- Torque
- Compressive force
Equipment of shear and Compression
ESCO
• High quality raw material is needed for TMP production

• In Northern Countries practically only Norway spruce is used
  - There has also been a growing interest to use Scots Pine in TMP refining
• Reason for different refining properties of Norway Spruce and Scots Pine are not known. There are several proposed hypothesis:
  - Extractives
  - Cell wall thickness
  - Microfibril angle
  - Other fibre differences

• ESCO is a good tool to study the effect of extractives on internal frictional properties of pulps
# Experiments

<table>
<thead>
<tr>
<th>Wood Species</th>
<th>Refining Stages</th>
<th>Total SEC (MWh/t)</th>
<th>CSF (ml)</th>
<th>Fibre Length (mm)</th>
<th>Acetone Dissolved Substances (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sawmill Pine</td>
<td>2</td>
<td>1.86</td>
<td>340</td>
<td>2.1</td>
<td>2.1 extracted</td>
</tr>
<tr>
<td>Thinning Pine</td>
<td>2</td>
<td>1.92</td>
<td>298</td>
<td>1.7</td>
<td>2.5 extracted</td>
</tr>
</tbody>
</table>

- Acetone extraction (modified SCAN CM:49)  
  100 g pulp, 1500 g acetone, 4 hours
Experiments

- Dry content of pulp about 14 %
- Temperature 120 °C
- Heating time: 15 minutes
- Compressive pressures: 1, 2, 3 and 4 bar
Volume Fraction of Pulp

\[ \varepsilon = \frac{V_{\text{fibre material}}}{V_{\text{total volume}}} = \frac{m}{\rho_{\text{fibre wall}}} \]

Disruptive Shear Stress

\[ \tau_{\text{max}} = \frac{2 \cdot T}{\pi \cdot r_{\text{max}}^3} \]
Compressibility of Pulps

- Thinning pine
- Sawmill pine
- Thinning pine - extracted
- Sawmill pine - extracted
Disruptive Shear Stress in Pulps

![Disruptive shear stress vs. volume fraction graph]

- Thinning pine
- Sawmill pine
- Thinning pine - extracted
- Sawmill pine - extracted
Disruptive Shear Stress in Pulps

![Disruptive shear stress vs pressure graph]

- **Disruptive shear stress** [N/m²] vs **pressure** [bar]
  - Symbols:
    - *o* thinning pine
    - *•* sawmill pine
    - *△* thinning pine - extracted
    - *■* sawmill pine - extracted
Conclusion

Acetone extraction did not affect compressibility of or disruptive shear stress in pine TMP pulps.

- This indicates that extractives do not cause ineffective refining by reducing friction between fibres.

Acknowledgement