Effects of Beating on Strength Properties of Hand Sheets of Unbleached Kraft Pine Pulp at Two Levels of Delignification

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Available online: April 30, 2014

To cite this article:

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Effects of Beating on Strength Properties of Hand Sheets of Unbleached Kraft Pine Pulp at Two Levels of Delignification

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(Received: 17 April 2014 / Accepted: 28 April 2014 / Published: 30 April 2014)

Abstract

In this study, two unbleached kraft pine pulp samples with different degrees of delignification as expressed by their respective kappa numbers of 17.30 and 29.30 were subjected to beating at different PFI mill revolutions of 0, 400, 800 and 1200 respectively. Pulp handsheets at each level were made and the strength properties of the formed handsheets assessed to evaluate the effect of variation of beating revolution and degree of delignification on pulp sheet strength. The study showed that there was a progressive increase in tensile and burst strength with increasing beating. However, higher strength values of 5.40 N.m/g and 5.46 N.m/g for tensile index and 4.08 Kpa.m²/g and 4.59 Kpa.m²/g for burst index were respectively attained earlier at 400 and 800 PFI beating revolutions using pulp of 17.30 kappa number, compared to pulp of 29.30 kappa number with equivalent strength values of 5.32 N.m/g and 6.08 N.m/g for tensile index and 3.53 Kpa.m²/g and 3.71 Kpa.m²/g for burst index which could only be attained at higher PFI mill beating values of 800 and 1200 revolutions respectively. The tearing strength values showed a general decreasing pattern from 1.34 – 0.64 mN.m²/g for pulp of kappa number 29.30, and 1.50 – 1.15 mN.m²/g for handsheets made from pulp of kappa number 17.30, as beating action increased. All the strength parameters assessed at 0.05 level of probability were significantly different. The study showed that the strength properties of unbleached kraft pine pulp sheets can be enhanced by increased beating of the pulp fibres, and that the strength properties of the handsheets likewise improve with progress in the degree of delignification of the pulp fibres that make up the sheet.

Keywords: Pulp Delignification, Kappa Number, Pulp Refining, Strength Properties, Pine Kraft Pulp
Introduction
Paper or pulp sheet properties depend not only on the inherent morphological characteristics of the fibres in the sheet, but to a great extent, are also determined by the pulping process employed to liberate the fibres as well as the subsequent process treatments the pulp may undergo under well-controlled processes such as bleaching, beating or refining (Noah, 2009). Pulping and bleaching are a delignification process. While pulping is the starting process, bleaching is seen as a continuation of the purification process aimed at removing residual lignin in the pulp. Therefore, the degree of delignification of a fibrous material is measured by the amount of residual lignin in the pulp as expressed by its kappa number. This means that even after chemical pulping, a process aimed at full delignification, some amount of residual lignin still remains in the pulp fibres. Thus, indicating that chemical pulping is essentially an operation to obtain pulp with target lignin content as measured by the kappa number (Kline, 1982). The presence of lignin in fibre inhibits inter-fibre bonding during felting or web conformability. Therefore, paper or pulp sheets made from lignin-containing pulp suffers greatly in strength, especially tensile and burst properties (Clark, 1978). Improvement in sheet strength can be enhanced by increased lignin removal (higher degree of delignification). According to Pan (2003), the improvement is attributed to increased fibre-to-fibre bonding which leads to enhanced strength in the pulp sheet. The removal of lignin (a hydrophobic substance) from the fibres renders the fibres more hydrophilic, thereby improving fibre bonding.

Beating or refining, a mechanically induced action on the pulp fibres, can make the fibres more conformable for paper making. Generally, fibre length, cell wall thickness, and to some extent, fibre lumen width affect paper properties such as mechanical strength, sheet formation, opacity and surface smoothness (Tiikaja, et al., 1998). Pulp fibres processed into paper without any form of mechanical treatment produce paper characterized by low strength, bulkiness, surface roughness and poor sheet formation, and not suitable for writing (Bhardwaj et al., 2004). However, when the pulp fibres are subjected to beating in a highly controlled manner, the tendency for these undesirable paper properties to develop is greatly reduced (Boywer, et al., 2007). This paper therefore examines the comparative effect of beating revolutions on strength properties of handsheets produced from unbleached Kraft pine pulp at two different levels of delignification (conventional pulp with kappa number 29.30 and soft pulp with kappa number 17.30).

Materials and Methods
Pines of 5years old were pulped according to Kraft cooking conditions. The cooked pulp was screened and the screened yield obtained was estimated for kappa number (TAPPI T236 om-99). The unbleached pulp was beaten in PFI mill according to TAPPI T248 sp-00. The handsheet for testing of strength properties was formed according to TAPPI T205 sp-02, while tensile, bursting and tearing strength as well as breaking length were determined according to TAPPI T494 om-01, TAPPI T403 om-97 and TAPPI T414 respectively. Thereafter, the two unbleached Kraft pine pulp samples with different degrees of delignification as measured by their respective kappa numbers 29.30 and 17.30 were subjected to beating at different PFI mill revolutions of 0, 400, 800 and 1200 respectively. Pulp handsheets at each level were made and the strength properties of the formed handsheets assessed to evaluate the effect of variation of beating revolution and degree of delignification on pulp sheet strength. Analysis of variance at 0.05 level of probability, followed by Duncan Multiple Range Test (DMRT) was conducted to assess the significance of parameters determined.

Results and Discussion
The study showed that the progress in delignification (higher to lower kappa number - 29.30 to 17.30), results in a corresponding high sheet strength value, especially in tensile and bursting properties but slightly in breaking length and tearing strength as shown in Table 1.

According to Surma-Slusaska, et al., (2003) at comparative high residual lignin content (kappa number 29.30), the fibres of the pulp are slightly stiffer, still covered with lignin and possess less tendency for fibril exposure on the fibre surface. Hence, the fibres will not easily collapse one on top of the other during web conformability for greater fibre-to-fibre contact for enhanced fibre bonding and improved sheet strength. Consequently, there is reduced fibre bonding accompanied by the attendant decrease in sheet strength. This is in line with the position of Kline (1982), who posits that the overall strength properties of paper (handsheet) are not only a function of the intrinsic strength of the fibres, but also, are dependent upon the amount of fibre bonding and the bonding distribution in the paper sheet. Fibre bonding and bond firming can be improved by subjecting the pulp fibres to beating (refining). During beating, the outer layer of fibre bonds is removed and the fibrils of the secondary wall exposed (external fibrillation). New external surfaces are created, which can participate in polyelectrolyte absorption and inter-fibre bonding. In addition, the fibres as a result of internal fibrillation become more hydrated (fibre swelling) and flexible, thus making them easily collapsible into a mat with more fibre contacts and born firming (Ahmad, et al., 2010).

Comparative assessment of parameters assessed in Table 1 shows that higher strength values for tensile and burst properties were attained earlier at 400 and 800 PFI beating revolutions using pulp of 17.30 kappa number, compared to pulp of 29.30 kappa number with which equivalent strength values could only be attained at higher PFI mill values of 800 and 1200 revolutions. According to Surma-Slusaska et al., (2003), at lower kappa number (17.30), less lignin content is found in the pulp fibres hence, high tendency for fibre flexibility and greater fibre surface area with exposed fibrils, while the pulp of 29.30 kappa number requires more mechanically induced action on the fibre for fibril exposure, greater fibre surface area for increased fibre-to-fibre contact and enhanced fibre bonding. Thus, pulp fibres with less lignin (kappa number 17.30) are...
easier to beat than pulp fibres with more lignin (29.30 kappa number). This corroborates the findings of MacLeod (1997) in his works on the beatability of Aspen-AS-AQ pulp with kappa number 25.80 and 17.70 respectively.

Table 1 also shows that beating revolution strongly affect handsheet strength. Biermann (1996) reported that strength of paper increases with pulp beating or refining since it relies on fibre-to-fibre bonding.

In Table 2 above, the analysis of variance (ANOVA) shows that at 0.05 level of probability for all parameters assessed during the study, there was significant difference in kappa number, beating revolution and interaction between them for tensile index, burst index, tear index and breaking length respectively. Follow-up Duncan Multiple Range Test (DMRT) as shown in Table 3 reveals that means with the same alphabets are not significantly different from one another. The relationship between the strength properties assessed and PFI beating revolutions of the unbleached kraft pine pulp at two levels of delignification is also presented graphically in Figures 1-2.

**Conclusion and Recommendations**

This study has shown that strength properties of a pulp sheet improve with progress in the degree of delignification of the pulp fibres that make up the sheet. The strength properties also varied differently with increasing beating on the pulp fibres. While tensile, bursting and breaking length values show increasing pattern to maximum with increasing beating, the tear strength is reduced with increased beating action. This is because tear strength is reduced by increased fibre bonding, the latter which is enhanced by increasing beating.

**References**


Tables

Table 1: Mean values of handsheet strength properties at different Kappa number

<table>
<thead>
<tr>
<th>Hand sheet properties</th>
<th>Beating revolution (PFI): basis weight: 72.03g/m²</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Kappa number 29.30</td>
</tr>
<tr>
<td></td>
<td>0</td>
</tr>
<tr>
<td>Tensile index (N/m/g)</td>
<td>1.20</td>
</tr>
<tr>
<td>Burst index (Kpa.m²/g)</td>
<td>0.65</td>
</tr>
<tr>
<td>Tear index (mN.m²/g)</td>
<td>1.34</td>
</tr>
<tr>
<td>Breaking length (km)</td>
<td>0.11</td>
</tr>
</tbody>
</table>

Table 2: Analysis of variance for parameters assessed

<table>
<thead>
<tr>
<th>SV</th>
<th>Df</th>
<th>Tensile index N/m/g</th>
<th>Tear index mN.m²/g</th>
<th>Burst index KPa.m²/g</th>
<th>Breaking length Km</th>
</tr>
</thead>
<tbody>
<tr>
<td>Kappa</td>
<td>1</td>
<td>10.473*</td>
<td>25.559*</td>
<td>16.101*</td>
<td>45.715*</td>
</tr>
<tr>
<td>Revolution</td>
<td>3</td>
<td>103.538*</td>
<td>7.177*</td>
<td>340.650*</td>
<td>128.326*</td>
</tr>
<tr>
<td>Kappa*Revolution</td>
<td>3</td>
<td>9.239*</td>
<td>5.853*</td>
<td>9.377*</td>
<td>42.034*</td>
</tr>
<tr>
<td>Error</td>
<td>32</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>39</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

* Significant at 0.05 level of probability.

Table 3: Duncan Multiple Range Test

<table>
<thead>
<tr>
<th>Revolution</th>
<th>Tensile index (N.m/g)</th>
<th>Tear index (mN.m²/g)</th>
<th>Burst index KPa.m²/g</th>
<th>Breaking length (km)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>1.0700a</td>
<td>1.4190b</td>
<td>0.5443a</td>
<td>0.953a</td>
</tr>
<tr>
<td>400</td>
<td>4.9900c</td>
<td>1.3806b</td>
<td>3.5328b</td>
<td>0.4704c</td>
</tr>
<tr>
<td>800</td>
<td>4.3400b</td>
<td>1.1480a</td>
<td>3.6605b</td>
<td>0.5228d</td>
</tr>
<tr>
<td>1200</td>
<td>5.5100c</td>
<td>1.0139a</td>
<td>4.1457c</td>
<td>0.3208b</td>
</tr>
</tbody>
</table>

Means with the same letter are not significantly different from one another.
Figures

**Figure 1:** Relationship between Tensile index and PFI beating revolutions of unbleached Kraft pine pulp at different levels of delignification

![Graph showing the relationship between Tensile index and PFI beating revolutions.](image)

**Figure 2:** Relationship between Burst and Beating Revolution of unbleached kraft pulp at different levels of delignification

![Graph showing the relationship between Burst index and Beating Revolution.](image)