Performance of abrasive segments in mechanical pulp refining. A review

Abstract
Innovative refiner segments with an abrasive surface designed for refining mechanical pulp are examined. The main purpose of these new segments is to improve the energy efficiency of the refining process. Various designs of abrasive segments have been invented and tested in laboratory, pilot, and industrial scale. According to reference publications, the experimental results indicate the potential for reducing energy consumption in refining process. However, refiners equipped with abrasive segments are difficult to control and the durability of abrasive segments during prolonged operation can not yet be guaranteed. In addition, pulp fibers are severely damaged during refining, leading to poor paper strength properties. Abrasive segments of this type have not yet been taken into industrial use. Therefore, further studies are needed to gain a profound understanding of the mechanism of abrasive treatment and to explore the possibilities of applying new technologies to achieve this aim. The present paper reviews various modifications of segments having abrasive surfaces and the results of trials, including the critical problems related to refiner operation and pulp quality, as a basis for further research.

Tiivistelmä
Pinnoitettut jauhinsegmentit mekaanisen massan jauhatuksessa
Katsaus käsittlee hiivalla pinnoituksella varustettujen uudenmallisten jauhinseg-
menttien toimivuutta mekaanisen massan jauhatuksessa. Uusien jauhinsegmenttien
päätarkoitus on parantaa jauhatuospesoon energiatehokkuutta. Erilaisia hiivalla pin-
noituksella varustettuja jauhinsegmenttejä on valmistettu ja niiden käyttöä on tutkittu
laboratorio-, koelaitos- ja teollisessa mitat-
kaavassa. Referenssjulkaisujen koetulokset
osoittavat, että uudet segmentit tarjoavat
mahdollisuuden jauhatuospesoon energiakan-
lulukseen parantumiseen. Hiivalla pinnoitu-
sella varustettuja jauhinsegmenttejä ei ole
yhtä oikein teolliseen käyttöön. Tarvitaan
lisätutkimuksia hiivan jauhinsegmentin
toimintaa säätelevän mekanismin perin-
pohjaiseksi selvittämiseksi, samalla kun
turkitaan uusia mahdollisuuksia ylläpitä
nityn tavoitteenvastuun saavuttamiseksi. Käsitte
oleva katsaus arvioi erilaisia muunnoks-
via hiivalla pinnoituksella varustetuista
jauhinsegmentteistä sekä niihin liittyviä tut-
kimustuloiksi, mm jauhimen toiminta-
na ja massan laatun on liittyviä kriittisiä ongel-
mia, jkatotutkimusten perustaksi.

Keywords:
Abrasive segments, grit materials, refining, mechanical pulp, energy consumption, pulp quality.

Introduction
Refiner mechanical pulp is the best type of pulp for producing high-grade magazine papers. The pulp has good strength properties and allows profitable paper production /1/. However, production of this type of pulp requires an electrical energy input of more than 3000 kWh/t, while theoretically calculated, the energy used in the refining process is about 0.22–300 kWh/t /2–5/. Previously, there was less concern about the energy consumption, because the wood raw material accounted for a larger share of the total production cost, while researchers concentrated on developing new methods to improve pulp quality. Since the 1970s, the energy cost has been seriously considered as a competitive factor, as the cost of me-
chanical pulp has turned out to be extremely vulnerable to the rising price of electricity. For example, at present, electricity accounts for 35–40% of the total production cost of thermomechanical pulp /6/. Thus, the rising price of electricity might become a critical factor in the future. To secure sustainable and competitive paper production based on mechanical pulp, the refining process needs to be developed to reduce the energy consumption and achieve better pulp quality.

One of the most important equipment parameters having a significant influence on energy consumption is the segment of refiner. The segment is vital in delivering and fibrillating fibers to the desired quality for making paper. Its pattern has a major effect on the dissipation of energy to the wood matrix and pulp fibers. Over the past few decades, refiner segments have been studied intensively. Several new designs have been introduced to improve the energy efficiency in the refining process, for example, a new geometry design and a modification of segment surfaces.

Recently, segments with a new geometry have been introduced for industrial use, e.g., LE™ segments /7/ and Turbine™ segments /8/. These segments apparently provide lower energy consumption. The principal idea of these segments is to reduce the residence time of pulp in the refiner. The short residence time contributes to high re-
fining intensity and a less turbulent flow, allowing energy to be efficiently transferred to wood fibers.

The other approach is the design of segment surfaces to be an abrasive as a means to increase the friction in the plate gap, and to direct energy intensively to breaking down the wood structure. Several techniques to produce an abrasive surface have been published, for example, filling the grooves and coating the surface of the refiner plate with abrasive materials. These segments have been tested in both laboratory and pilot scale. The results indicate their potential for reducing the energy consumption. However, these segments have not been taken into industrial use because of problems with the operation of the refiner, the operating life of segments and the severe degradation of pulp quality. At present, an innovative technolo-
gy for metal base coating is available. It could be used to manufacture different →

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abrasive layers on the segment surfaces and to extend their operating life. Combining the new geometry of the segment design with the surface modification is a challenging task, aiming for a highly energy-efficient process.

The objective of the present paper is to review the potential use of these innovative abrasive segments in mechanical pulp refining. Various modifications of segments with abrasive surfaces are examined and test results presented. The critical problems in the operation of refiners equipped with abrasive segments and the effects of abrasive treatment on pulp quality are discussed as a basis for further development.

Flat abrasive segments

Several new designs of flat abrasive segments have been presented. Generally, the segments are composed of abrasive surfaces, which partially or completely replace the conventional bars and grooves. The abrasive surfaces can be located in the inner or outer zones of the segments. Marton and Brown’s early invention of abrasive segments was patented in 1980, followed by Sunyo’s and Pregetter’s segments. These segments have been tested in the main refining line of a mechanical pulp mill and in reject pulp treatment.

Marton and Brown’s abrasive segments

Marton and Brown’s /9/ patented flat abrasive segment consists of a breaking bar at the center and flat abrasive surfaces on the inner and outside zones, as shown in Fig. 1. The abrasive surfaces were made from 36-mesh tungsten carbide grits, which were bonded onto base segments using a brazing method. The bonding material was a nickel-chromium-boron matrix. Later on, Sharpe and Sandven /10/ introduced a laser coating method (Fig. 2) to improve the bondability between the abrasive materials and the base segments. This technique was carried out by directing a laser beam onto the base plate, creating a thin molten layer on its surface. After the laser treatment, the abrasive materials were deposited and bonded strongly to the base segments.

According to Marton and Brown’s patent /9/, the trial with this segment was performed in a two-stage refining process. The abrasive segments were installed in the first-stage refiner operated under pressurized conditions. Refining conditions were controlled to maintain a temperature of 120–130 °C and a machine speed of 1200 rpm. The second-stage refiner was equipped with conventional segments and operated under atmospheric pressure. Southern pine chips were used as raw material. This trial gave encouraging results, showing that the flat abrasive segments consumed 17% less energy than conventional segments, while maintaining similar pulp quality.

In 1987, Stationwala /11/ tested these segments in mill scale. The abrasive layer was made from 36-mesh tungsten carbide grits, which were bonded to base segments at the outer zone by a plasma-spraying method. The segment is shown in Fig. 2. The density of active grits was about 80 grits/cm². This trial was performed in a second-stage refiner operated under atmospheric pressure. A Sprout Waldron refiner (42–1B) was used for testing. The abrasive segments were mounted on the stationary disc, while the rotor side was equipped with the conventional segments. The first-stage pulp was produced from spruce and in part from balsam fir wood chips. During the trial, the refiner was found to be unable to withstand high loading capacity. The solution was to replace the conventional segments on the rotor side with the segments having a wider intermediate groove. This combination allowed high loading capacity, while producing pulp with lower energy consumption, as shown in Fig. 3. The pulp produced with abrasive segments had higher tensile strength and light scattering, but lower tear strength than conventionally produced pulp. According to the author,
over a trial period of 7 hours there was no noticeable segment wear, but obviously the segments' services lifetime needs to be evaluated over a longer operating period.

A further trial with the flat abrasive segments was carried out in 1994 by Stationwala and Miles [12]. The trial was conducted on both single- and double-disc refiners. The single-disc trial was conducted with a second-stage Sprout Waldron refiner (42–1B) at mill scale. The abrasive segments were fitted on the stator facing the conventional segments on the rotor side. The refiner was operated under atmospheric pressure. According to the authors, the abrasive filled segments showed almost similar performance to that of the conventional segments. A reduction in energy input could not be achieved, as shown in Fig. 4. The double-disc refining was done at pilot scale, using the institute's Bauer 400 refiner and performed in second-stage refining. The refiner was equipped with abrasive segments on one side and the other side was equipped with conventional segments. The authors reported circumferential fluctuations between the grits and the opposite bars. The refiner required higher shaft thrust to achieve a given motor load, and consumed more energy to produce the pulp with target freeness, as shown in Fig. 4. Based on the results of the single- and double-disc refiner trials, the authors concluded that there are no apparent advantages of using these segments in a high-consistency refining process.

Sunyo Kokusaku Pulp's abrasive segments

Sunyo Kokusaku Pulp Co. [13, 14] patented a flat abrasive plate without bars and grooves for refining mechanical pulp in low-consistency conditions. The configuration and segments are shown in Fig. 5. The basic concept and testing of this segment were presented by Kano et al. [15] in 1983. According to the authors, refining of mechanical pulp at high consistency is inefficient in terms of energy consumption. The refining should be performed under low-consistency conditions and it should be a relatively gentle, with a large number of impacts to maintain fiber length and ensure homogeneous treatment. According to the authors, increasing the number of bar elements is a favorable means to increase the number of impacts, but in practice this can not be done with conventional steel segments. To solve this problem, the segments were designed to have an abrasive surface without bar elements and grooves. The width of the gap between the abrasive segments was of the order of a fiber's diameter. There is no information how to control the gap clearance between the abrasive plates. The authors claim that the segments provided a large energy saving without any loss in the strength properties of paper, and further work is being conducted to develop an industrial application. So far, this segment has not been taken into industrial use.

Pregetter's abrasive segments

Pregetter et al. [16] introduced abrasive segments for refining under various levels of consistency from 4 to 30%. The abrasive surfaces were made from a porous metal having an average pore size of 2 mm. Grooves were designed between the abrasive area with plugs inside them to control the pulp flow. This segment is shown in Fig. 6.

The segment was tested with various types of raw material, i.e., bleached softwood Kraft pulp (BSWK) and bleached chemi-thermochemical pulp (BCTMP) refined at low consistency, and reject PGW and TMP pulps refined at medium and high consistency. The segments were installed both on the rotor and stator sides of refiners. According to the authors, in low-consistency refining, the BSWK pulp was harshly treated, whereas the BCTMP pulp showed fast development of drainability and strength properties. Refining of PGW and TMP pulps showed positive results under an operating consistency of 10%, producing fast development of pulp freeness and paper strength properties at the same energy consumption as conventional segments. The machine suppliers, Voith Sulzer Stoffaufbereitung GmbH, was involved in this experimental work. However, there is no further information on any industrial trials.

Abrasive material on bar surfaces

Segments with an abrasive material on the bar surfaces have been manufactured by coating and localizing methods. Their patterns are similar to those of traditional segments, but the bar surfaces are modified. According to the reference publications, the segments have been tested in both low- and high-consistency refining of mechanical pulp.

Coated bar segments

Stationwala and Miles [12] manufactured segments having a coated abrasive layer on the bar surfaces in 1994. The coating was done at the intermediate refining zone by plasma spraying, using 36-mesh tungsten carbide grits as a coating material. The coated bar segment is shown in Fig. 7. The trial with this segment was performed in second-stage refining of TMP pulp. The abrasive segments were installed in the stationary disc against conventional segments on the rotor side. According to the authors, this work was not successful because of problems with the rubbing of segments between rotor and stator. The motor load could be only 60% of the normal load. The pulp produced by these segments gave lower tensile and tear strength than pulp produced by conventional segments. There are no differences in energy consumption between coated abrasive segments and conventional segments. Accordingly, the authors state that there are no specific advantages of using these segments.

Localized surface roughness

Dodd and Wasikowski [17] have patented refiner segments with localized surface roughness in 1997. According to the inven-
tors, the basic idea of this segment is that the refining action principally occurs on the outermost surface of the refiner bars. The surface roughness serves to retain the fibers on the surface and to build up a fiber pad to promote refining. The method to produce the surface roughness includes depositing or coating of abrasive materials on the top of the bars, creating a relatively thin abrasive layer which is rapidly worn off during refining. According to the patent documentation, embodiments of abrasive layers into the bars would be the solution to make the abrasive layer durable. The embodiments can be made by depositing abrasive materials into the center of the bars or placing abrasive material on the edges of refiner bars, as shown in Fig. 8. Unfortunately, the patent documentation does not include any experimental data. However, the inventors mention that this type of segment can be used in low- and high-consistency refining.

**Abrasive in segment grooves**

A simple solution to create abrasive surfaces on the segments is filling the abrasive materials into the segment grooves, or forming the abrasive layer on the groove surfaces. There are several patents for refining of mechanical pulp in low- and high-consistency conditions with this type of segment. The first patent was filed by Oji Paper Co, in 1979. Comprehensive works by Miles and May were published in scientific journals in 1984.

**Filled groove segments**

The first filled groove segment was patented by Oji Paper Co, in 1979 [18]. Originally, it was made for use in stock preparation under low-consistency refining conditions. At the same time, Miles and May [19] also developed an abrasive segment for wood chip refining. Called “filled segment”, it was based on a concept similar to that of Oji Paper’s patent. However, the first paper in a scientific journal was published by Miles and May in 1984. The segment was simply made by filling the grooves with 60-mesh silicon carbide grits mixed with an epoxy resin. The filling was done across the entire length of the refining zone. The packing material was radiused to a level about 0.75 mm below the bar surfaces, as shown in Fig. 9.

The segment was tested in RMP and TMP refining. Black spruce chips were used as a raw material. According to Miles and May [19], refining tests with RMP showed potential for reducing the energy consumption by approximately 8%, as shown in Fig. 10. The gap clearance was about 100 μm smaller than for standard segments to maintain a given motor load and ensure less variation of movements (Fig. 10). In TMP refining, the segment was first tested in the first-stage refiner. It was found to result in problems with poor loading capacity of the refiner, and the refiner consumed a high amount of electrical energy. The authors assume that the filled segments might have interfered with the flow of steam through the refining zone. The solution was to fit the segments in the second-stage refiner. However, the results were similar to those obtained with conventional segments. In addition, Miles et al. [20] made the experiment to find out the refining mechanism under a pressurized condition by filling the grooves in various locations. It was found that the different locations of the filling zones, e.g., intermediate and fine bar zones, and the installed sides of the segments on both the rotor and stator, have a significant influence on the transport of pulp through the refiners, and consequently, on the energy consumption and pulp quality.

Mill-scale trials with these segments were carried out by Stationwala and Miles [12] in 1994. The abrasive segments were made by depositing abrasive material in the grooves at the intermediate zone of the conventional segments. The segments were filled by using a plasma spray process. The filled abrasive segment is shown in Fig. 9. The trial was performed in single-disc mode in a second-stage refiner. The segments were installed on the stationary disc against the conventional segments fitted on the rotor side. The refiner was operated under atmospheric conditions. According to the results, the abrasive filled segments showed almost the same performance as the conventional segments. Over the testing period of 485 hours, small chunks of filled material broke loose from the grooves, gradually reducing the operating lifetime of the segments. In their conclusions, the authors suggested that there was no apparent advantage of using these segments in high-consistency refining.

**Rough edged segments**

Waskiwski [21] invented the “rough edged refiner segment cutter bar” patented in 1992. The abrasive layers were made by mixing grit materials with a phenolic urethane, and then applying the material on the groove surfaces of segments, as shown in Fig. 11. According to the patent documentation, these segments were designed to promote the fibrillation of fibers in the TMP refining. There are no experimental data in the patent documentation.

**Conclusions**

Different designs of abrasive segments have been invented for mechanical pulp refining, i.e., flat abrasive segments, bar abrasive seg-

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*Fig. 7. Refiner segments with an abrasive material on bar surfaces [12].*

*Fig. 8. Localized surface roughness in bar elements [17].*

*Fig. 9. Abrasive filled segment for a wood chip refiner presented by Miles and May [19] (left) and abrasive filled segments used in mill scale trials and made by depositing plasma abrasive materials into the grooves [12] (right).*
ments, and filled-groove abrasive segments (Table 1), but none of these have been taken into industrial use so far. The abrasive segments have been partially tested in first-stage refining. Most of the trials have been performed in second-stage refining. Some trial results indicate potential for reducing the energy consumption. However, numerous problems have occurred during the tests. For example, the refiner was found to be unable to handle high loading capacity, and circumferential fluctuations and rubbing were noted between segments on the rotor and stator. In addition, the abrasive layers were found to wear off and fibers suffered severe damage, leading to low paper strength. In low-consistency refining of mechanical pulp, abrasive segments have been used to fibrillate high-freeness pulp. The possibility for reducing energy consumption has not been confirmed, but experimental data supporting this assumption is lacking.

References


Table 1. Researches and developments of refiner segments having abrasive surfaces for mechanical pulp refining during the past three decades.

<table>
<thead>
<tr>
<th>Year</th>
<th>Designs of abrasive segments</th>
<th>Application areas and refining conditions</th>
<th>Potential for energy saving</th>
<th>References</th>
</tr>
</thead>
<tbody>
<tr>
<td>1979</td>
<td>Filled groove segments</td>
<td>Stock preparation, low consistency refining</td>
<td>No information</td>
<td>Koid e al. /18/</td>
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<tr>
<td>1980</td>
<td>Flat abrasive segments</td>
<td>Low consistency refining</td>
<td>Yes</td>
<td>Kanou et al. /13, 14/</td>
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<td>1980</td>
<td>Flat abrasive segments</td>
<td>First-stage TMP refining, single disc refiner, lab scale</td>
<td>Yes</td>
<td>Marton and Brown /19/</td>
</tr>
<tr>
<td>1984</td>
<td>Filled groove segments</td>
<td>First-stage RMP refining, single disc refiner, lab scale</td>
<td>Yes</td>
<td>Miles and May /19/</td>
</tr>
<tr>
<td>1984</td>
<td>Filled groove segments</td>
<td>First-stage TMP refining, single disc refiner, lab scale</td>
<td>No</td>
<td>Miles et al. /19, 20/</td>
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<td>1987</td>
<td>Flat abrasive segments</td>
<td>Second-stage, atmospheric pressure, single disc refiner, mill scale</td>
<td>Yes</td>
<td>Stationwala /11/</td>
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<td>1992</td>
<td>Rough edged refiner segment cutter bar</td>
<td>TMP refining</td>
<td>No information</td>
<td>Wasikowski /11/</td>
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<td>1994</td>
<td>Flat abrasive segments</td>
<td>Second-stage, atmospheric pressure</td>
<td>No</td>
<td>Stationwala and Miles /12/</td>
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<td>1997</td>
<td>Filled groove segments</td>
<td>Single disc refiner, mill scale</td>
<td>Yes</td>
<td>Dodd and Wasikowski /17/</td>
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<tr>
<td>1997</td>
<td>Abusive on bar surface</td>
<td>Low- and high-consistency refining</td>
<td>No information</td>
<td>Pregert et al. /16/</td>
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<td>1999</td>
<td>Flat abrasive segments</td>
<td>Reject refining (PGW, TMP) Refining consistency of 10%</td>
<td>Yes</td>
<td>Pregert et al. /16/</td>
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Received January 21, 2008