Characterization of Chipper Knife Wear During Chipping Eucalyptus Wood

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Abstract. In a large-scale pulp and paper industry, good quality chips play a critical role in determining the pulp making process. Several factors affect the resulting quality of chips in the wood chipping process; among of them are the chipper knife sharpness and wear. This research examines the difference between sharp knife and worn-out knife based on the image analysis and chip quality eva uation once used for chipping Eucalyptus wood. Through the image analysis with electron microscopy, it is noted distinct differences between sharp and worn-out knives. The progression of wear, primarily caused by abrasion, friction, and heat during the chipping process, is clearly represented. With Scandinavian standard screening method, it is shown acceptance rate of the chips over time; in which such the chip acceptance rate decreases by 2.26% as the knives wear down.

Keywords: Chipper, Wood chip, Chip quality, Wear out, Morphology.

1   INTRODUCTION

Up to now, pulp and paper industry continues to grow globally. In 2021, nominal value of global forest products export reach USD 286 billion, with paper and paperboard contribute 35 percent of the total value, and pulp contribute around 13 to 19 percent. Total production in 2021, both paper and paperboard, and wood pulp, also have increased its number prior to 2020. Paper and paperboard have increased its production by 4.4 percent to 417 million tons compared to 2020, while wood pulp production increased by 2.7 percent to 194 million tons in 2021. Despite the shift towards digital formats for paper-based activities such as education and news consumption, other aspect of life are not only maintaining demand for paper products but actually increasing it. For instance, the rise in online shopping and shipping has led to a growing need for packaging materials, further boosting the industry's relevance and demand [1].

Paper and paper board are primarily made from wood pulp. In order to make a good quality pulp, good quality wood chips are needed. Wood chips are generally classified into several classes, i.e., the accept chips and rejects. Accept chips is the desirable, highquality chips that need to be maximized to ensure uniform cooking during pulp

production, while the rejects, which should be minimized, consist of oversized and overthick chips as well as smaller pin chips and fines. Generally, a larger reject, which consist of oversize chips and overthick chips, require additional processing to reshape into a more proper size. This effort not only increases costs but can also cause fiber damage during reshaping, which in the end can lower pulp yield and strength. If these oversized chips remain too large, they may also result in uneven cooking and ultimately become rejects during the pulp-making process. On the other hand, smaller rejects, like pin chips and fines, tend to clog the digester during pulp cooking, which could lead to reduced yield and decreased pulp production [2, 3].

In earlier work, an experiment has been conducted using the to make pulp using Eucalyptus hybrid as the hard wood [4]. This experiment shows that once the overthick chips being ignored or not processed before cooking the pulp, the pulp yield was lower compared to overthick chips that had been cracked or regular accept chips. Even when compared to pulp produced from pin chips, a smaller form of reject chips, the pulp yield from untreated overthick chips was lower. In addition, cooking overthick chips required more chemicals, leading to a greater environmental impact [4]. Another work using softwood produced similar results, indicating that cooking with reject chips reduces pulp yield, which in the end could lead to increased costs due to the need for additional wood, higher chemical consumption, and greater overall production expenses [5].

To reduce rejects and optimize chip quality, the chipping process must be carefully controlled, with the chipper knives as one of the items that should be put into the attention. Knives is a part of the chippers that come into contact directly with the wood during the chip making process. The knives' sharpness affects the force required for shearing the logs into chips. The dull or worn-out knives would not only be potentially resulting in lower force, but also uneven chip surface, that would eventually increase the number of rejects. The sharpness angle of the knives plays a key role in wear rate; while a smaller angle can increase the cutting force, it also makes the knives more susceptible to damage. [2, 3, 6].

An experimental work had also been conducted using small sized disc chipper and drum chipper. This experiment revealed that knife wear has a more dominant effect on product quality than factors such as wood species or the use of a piece breaker, though these also have a significant impact [7]. The experiment using drum chipper also showed a decreased chip quality. In a processing with hardwood, there was a tendency to produce more oversized chips as rejects, while softwood chipping resulted in more pin chips. To mitigate this problem, a frequent knife sharpening is needed, preferably using wet sharpening rather than dry sharpening method for a better result [8, 9]. While most of the earlier experimental works were conducted with small size chippers, this present study examines the large, industrial-scale chipper. In this research, the relationship between the condition of worn-out knives and the chip quality produced by these industrial chippers was determined. The wear of the knives in this research was studied through the micrographs obtained from an electron microscope. Unlike previous experiments that primarily focused on the differences in chip quality between sharp and wornout knives, this research adopts a different approach. It not only compares chip quality during the use of sharp versus worn-out knives but also analyzes the regression of chip quality over time—from the moment the knives are sharp to when they become worn out.

2 MATERIALS AND METHODS

2.1 Materials and Equipment

The experiment in this research was conducted using horizontal-fed disc chipper HHQ Chipper Model EXL21, manufactured by Finish company Andritz, such as shown in Fig. 1a. This chipper used was a horizontal chipper type, where the logs was brought horizontally using a chain conveyor into the chipper to be cut through feed spout in the chipper cutting area (Fig. 1b.). This chipper featured with one chipper disc that hold 21 pieces of insert-type knives which rotated at 220 rpm and was powered by four motors, each with a capacity of 400 kW. The feedstock material used in this experiment was Eucalyptus logs, which were commonly utilized in pulp industry. The logs could be used directly or stored until needed. Logs condition must be free of twigs, branch, and roots, also already being debarked before being used in the experiment. The average diameter for this log was 18 cm and having moisture contents of around 45% and density of approximately 500 kg/m^3.
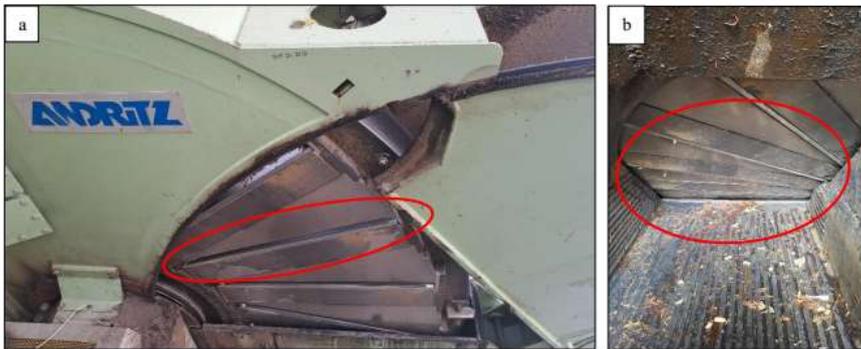

Fig. 1. Andritz HHQ-Chipper Model EXL21: (a) Knife changing area, (b) wood cutting (feeding) area.

2.2 Characterization of The Worn Knife Using Scanning Electron Microscope (SEM) Analysis

Knife testing using the Andritz HHQ chipper was conducted from the moment the knives were changed until they became worn out and could no longer make effective cuts. Two worn-out knives were selected from the set of 21, cleaned with water, and examined with a portable microscope to verify their worn-out positions. The worn areas were marked with a 10 mm × 10 mm designation and cut for testing with a Scanning Electron Microscope (SEM) for imaging analysis. The same procedure was followed for the sharp knives. For the knife imaging analysis, SEM was performed to detect any defects or broken parts that occurred during chipping, allowing for a comparison with the sharp knives. The knife samples were examined using a JCM-7000 Scanning Electron Microscope (JEOL, Japan) operating at 15 kV.

2.3   Quality Analysis of The Chips Processed with The Sharp and Worn Knives

Chips were collected from the chute of the chip conveyor after the chipper, with each sample weighing approximately 20 kg. This sampling was conducted hourly until the chipper knives wore out and could no longer perform chipping. From each 20 kg sample, 10 liters of chips were taken after stirring to ensure homogeneity. The final 10-liter sample was then classified using the Andritz Scan Chips (Andritz, Finland). This equipment scanned the chips and analyzed their size and shape to assess chip quality and provide results. Samples were taken on an hourly basis from the start of chipping until the chipper knives wore out. The classification in this research referred to SCAN-CM 40:01 standard for wood chip size distribution for pulp production, dividing the chips into six categories, as shown in Fig. 2. These categories included oversized chips, overthick chips, large accept chips, small accept chips, pin chips, and fines. This cycle was repeated five times on different days to gather additional data and ensure validity.
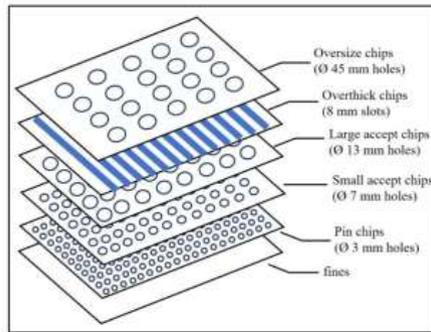

Fig. 2. Illustration of screens and fines tray in the chip classifier using SCAN CM 40-01 standard.

3   RESULT AND DISCUSSION

3.1   Image Analysis of The Sharp and Worn Knives with Electron Microscope

In the pulp and paper industry, chip quality, especially the accept chips, is a critical factor for producing high-quality pulp [2, 3]. The sharpness of the knives significantly contributes to and closely relates to the chip quality generated by the chipper. Over time, as chipping occurs, particularly during extended operations, the chipper knives will wear out, leading to observable changes in their shape. This experiment analyzes the worn-out condition of the knives by comparing the microscopic images of sharp and worn-out knives. A Scanning Electron Microscope (SEM) was used to capture images of both types of knives, with Secondary Electron Detector (SED) as the more suitable mode for inspecting the topography of the sample's surface [11].

A sharp knife, such as shown in **Fig. 3a**, exhibited diagonal marks from the sharpening process that had been previously performed using a knife grinding machine. These marks indicated that work had been done to shape the knife to achieve the correct angle. The horizontal mark in the middle, visible in both **Fig. 3a** and **Fig. 3b**, represents

the sharp edge of the knife. This sharp edge is responsible for shearing the logs into chips.

The worn knife, as shown in **Fig. 3c** and **Fig. 3d**, had lost most of its diagonal marks, retaining only a small amount. This wear is primarily due to abrasion and friction that occur during the chipping process, even though these areas were not the main sharp edges. The horizontal mark, which indicated the sharp edge, was completely gone. A distinct difference can be observed when comparing **Fig. 3a** and **Fig. 3c**; at which the sharp edge of the knife was deformed with a rounded shape as it was worn down. This rounding results from the frequent contact and friction between the knife and the logs over time. During the log cutting process, the edge of the knife was not only abraded, but also heated, which also further contributed to the loss of its sharpness. **Fig. 3c** and **Fig. 3d** also shows damage part of the knife. The damage might occur because of two factors. First, the knife could be impacted by materials other than logs, such as stones, sand, or soil. In addition, parts of the logs, such as wood knots, may possess greater hardness and irregular shapes, making them more challenging to cut. These factors can lead to a reduction in the knife's service life [12].
Second, deformation may occur due to the heat generated from friction during the chipping process. Chipping operates at high speeds and is cooled only by water spray using room temperature clean water, resulting in significant heat generation that can contribute to the knife edge deformation.

3.2 The Quality Analysis of The Chips Processed with The Sharp and Worn-Out Knives

The chip samples that were gathered and classified using Andritz Scan Chips were then assembled and analyzed. The first step of the analysis in this research was to normalize the data to remove outliers. This step was conducted by using upper and lower boundaries defined by a difference of two times the standard deviation from the average value, as shown in **Table 1**. It was noted that some data points were outliers and needed to be excluded. The normalized data from this experiment is presented in **Table 2**; indicating the improved consistency as the standard deviation decreased from 2.16 to 0.74.
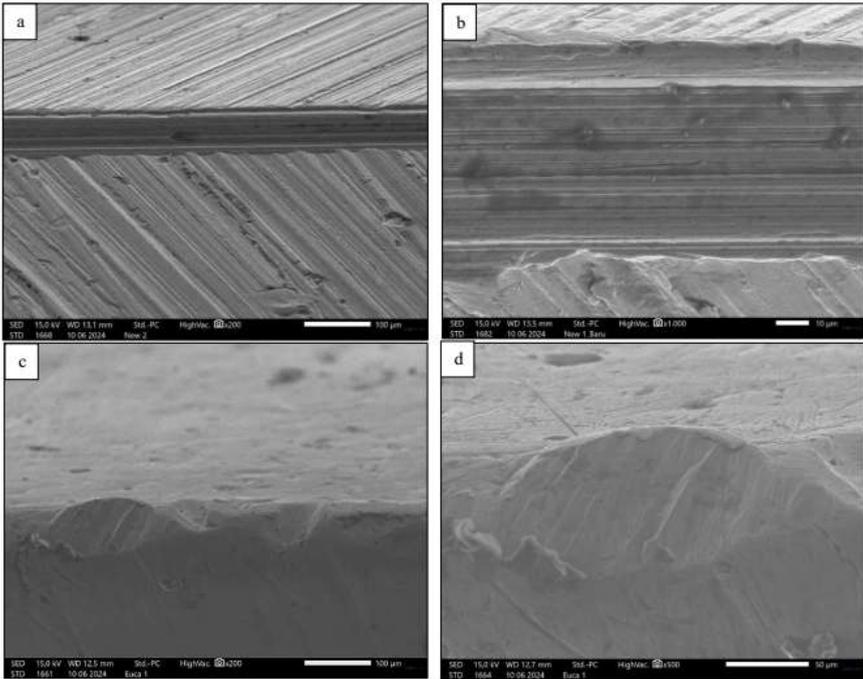
Fig. 3. Electron micrographs of: (a) Sharp knife with mag. 200x, (b) Sharp knife with mag. 500x, (c) Worn-out knife with mag 200x, and (d) Worn-out knife with mag. 500x.

Table 1. Accept chips fraction after five days sampling

Hour	Total Accept Chips 1 (%)	Total Accept Chips 2 (%)	Total Accept Chips 3 (%)	Total Accept Chips 4 (%)	Total Accept Chips 5 (%)
1.	91	83.9	88.2	89	89.4
2.	90.9	85.7	86.8	90.7	83.4
3.	88.1	88.9	88.1	89.5	90.5
4.	90.9	86.9	89.2	88.8	88.8
5.	88.4	88.4	89	86.8	89.2
6.	90.9	87.7	89.1	87.5	90.7
7.	84.2	88.6	88.2	87.3	90.9
8.	87.9	-	88.5	-	88.7
9.	87.7	-	-	-	87.6
Average	88.89	87.16	88.39	88.51	88.80
Standard deviation	2.16	1.68	0.73	1.28	2.16
Upper Bound	93.20	90.52	89.84	91.08	93.12
Lower Bound	84.58	83.80	86.93	85.95	84.48

Table 2. Accept chips fraction after normalization and rearrangement

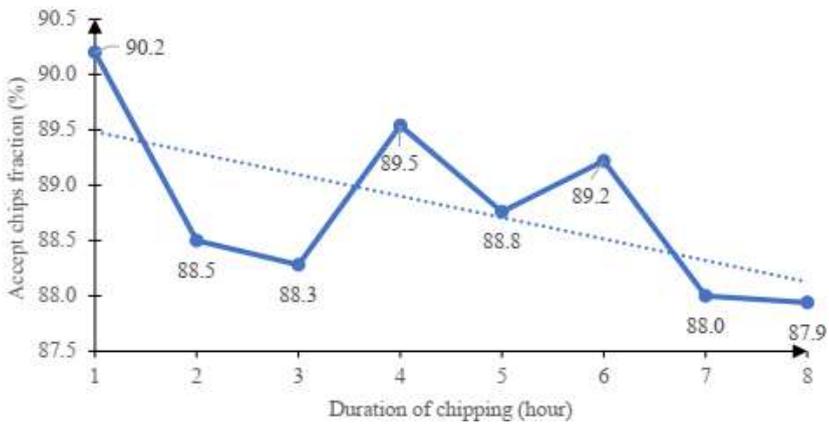| Hour	Total Accept Chips 1 (%)	Total Accept Chips 2 (%)	Total Accept Chips 3 (%)	Total Accept Chips 4 (%)	Total Accept Chips 5 (%)	Average Accept Chips (%)
1.	91				89.4	90.2
2.	90.9	83.9	88.2	89	90.5	88.5
3.	88.1	85.7	88.1	90.7	88.8	88.28
4.	90.9	88.9	89.2	89.5	89.2	89.54
5.	88.4	86.9	89	88.8	90.7	88.76
6.	90.9	88.4	89.1	86.8	90.9	89.22
7.	87.9	87.7	88.2	87.5	88.7	88
8.	87.7	88.6	88.5	87.3	87.6	87.94
Average	89.48	87.16	88.61	88.51	89.48	88.81
Standard deviation	1.46	1.68	0.44	1.28	1.07	0.74
First and last data difference	-3.3	4.7	0.3	-1.7	-1.8	-2.26

Fig. 4. Average accept chips regression per hour

The average data indicated a decrease of 2.26 percent between the first hour of chipping and the last hour. While this may not seem significant, in large-scale production, where more than 7,000 tons of logs are chipped daily, such a small difference is considered of importance, as it can accumulate into a substantial loss of fiber and the pulp production over the year. A regression analysis was used in this analysis and the result is shown in **Fig. 4**, indicates that the fraction of accept chips continues to decrease over time.

For the rejects, using the data point that already marked as outlier in accept chips, that same point also being removed in large-size rejects (consist of oversize chips and overthick chips) and small-size rejects (consist of pin chips and fines). The number of large-size rejects increased by 1.87 percent average between the first hour of chipping and the last hour of chipping. As for smallsize rejects, the number also increased by 0.41 percent between the first hour of chipping and the last hour of chipping. Those result can be seen in **Table 3** and **Table 4**. The result of regression of the data obtained from the rejects can be seen in **Fig. 5.** and **Fig. 6.** As can be seen for the regression of large-size rejects and small-size rejects, both exhibit a tendency to increase, although

not as steeply as the decline in accept chips quality. It is interesting to see because from other experiment, usually for hardwood, the reject increment that usually occurs is large-size rejects, but this experiment shows that small-size rejects also showing increase in regression. But still as can be seen from the increased numbers of rejects, large-size rejects still holding its place compared to small-size rejects, and align with other previous experiment [8].

Table 3. Large-size rejects fraction after normalization and rearrangement

Hour	Total Large-size Rejects 1 (%)	Total Large-size Rejects 2 (%)	Total Large-size Rejects 3 (%)	Total Large-size Rejects 4 (%)	Total Large-size Rejects 5 (%)	Average Large-size Rejects (%)
1.	4.3				6	5.15
2.	6.4	12.8	7.3	7.3	5.6	7.88
3.	7.9	10.6	8.4	4.5	6.7	7.62
4.	4	6.2	5.6	6.3	8.8	6.18
5.	6	9.1	6.4	7	5.9	6.88
6.	5.4	7.9	6.9	9	7.2	7.28
7.	6.7	6.5	7.2	7.2	8.9	7.3
8.	6.6	5.2	6.6	8.7	8	7.02
Average	5.91	8.33	6.91	7.14	7.14	6.91
Standard deviation	1.21	2.50	0.80	1.39	1.22	0.82
First and last data difference	2.3	-7.6	-0.7	1.4	2	1.87

Table 4. Small-size fraction after normalization and rearrangement

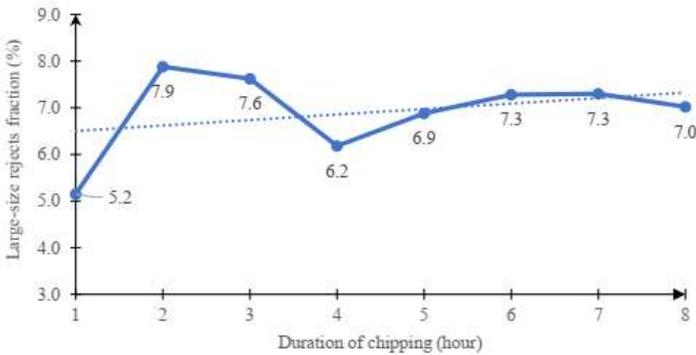| Hour	Total Small-size Rejects 1 (%)	Total Small-size Rejects 2 (%)	Total Small-size Rejects 3 (%)	Total Small-size Rejects 4 (%)	Total Small-size Rejects 5 (%)	Average Small-size Rejects (%)
1.	4.7				4.6	4.65
2.	2.7	3.3	4.5	3.7	3.9	3.62
3.	4	3.7	3.5	4.8	4.5	4.1
4.	5.1	4.9	5.2	4.2	2	4.28
5.	5.6	4	4.6	4.2	3.4	4.36
6.	3.7	3.7	4	4.2	1.9	3.5
7.	5.4	5.8	4.6	5.3	2.4	4.7
8.	5.7	6.2	4.9	4.1	4.4	5.06
Average	4.61	4.51	4.47	4.36	3.39	4.28
Standard deviation	0.99	1.05	0.52	0.49	1.07	0.50
First and last data difference	1	2.9	0.4	0.4	-0.2	0.41

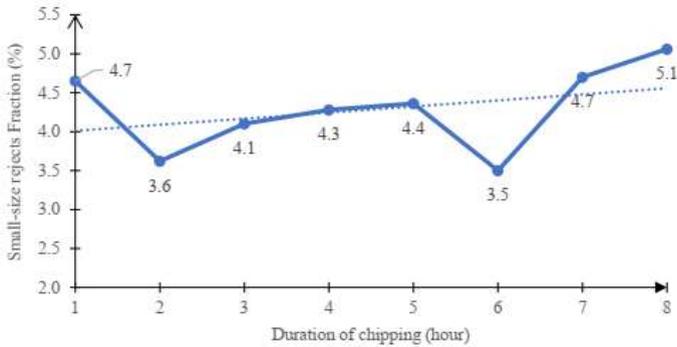**Fig. 5.** Average large-size rejects regression per hour

Fig. 6. Average small-size rejects regression per hour

The overall increase in rejects aligns with the wear of the chipper knives. As the wear progresses, the chipper loses its ability to cut the logs with the quality it is designed to achieve. The unevenness of the chipper knives, as illustrated in **Fig. 3**, may reduce the shearing and cutting force overtime as the sharp edge deteriorates, particularly as the chipper approaches the end of its cutting capability. This unevenness in knife sharpness, resulting from wear, leads to a greater proportion of unevenly cut chips or rejects [3]. This is also evident in the oversized chips shown in Fig. 7a, which exceed 45 mm in size, and in **Fig. 7b**, where the ends of the chips begin to bend, indicating a poor shear cut process. This is distinctly different from the accept chips depicted in **Fig. 8**, which exhibit a smoother surface and an acceptable size range (between 7 mm and 45 mm) as a result of clean cutting and shearing. Other factors such as wood aging, moisture content, knife cooling, and more knife settings also might have contribution in wearing-out the knives and worth to experiment in the future.
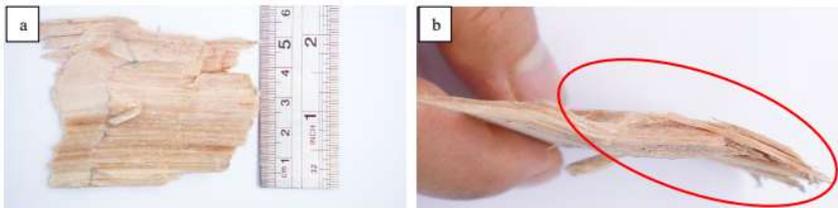

Fig. 7. Large-size rejects chip: (a) Oversize chip measurement, (b) Broken end in oversize chips

Fig. 8. Clean cut and/or sheared large accept chips and the measurement

4   CONCLUSION

This experiment shows the declining chip quality overtime in response of worn-out knife. There are several outcomes from this experiment:
1. There is a distinct difference between sharp and worn-out knives at the microscopic level, demonstrating that the sharp edge of the knives is lost as they become worn.
2. Chip quality tends to decrease over time, particularly in the last two hours of chipping. This phenomenon corresponds with the wear progression of the chipper knives.
3. Reject fraction that occurs dominated by large-size reject (combination of oversize and overthick), align with other experiment that using hardwood, even though small-size reject also showing a small increment tendency.

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