Effect of Fungal Degradation of Wood Chips on Pulp and Paper Properties at Panafrican Paper Mills, Webuye, Kenya

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Abstract: Losses caused by wood decay fungi in a *Pinus patula* chip pile in storage were studied for six months at Panafrican Paper Mills, Webuye, Kenya. The losses were quantified in terms of pulp yield, pulp quality, and paper properties. Light microscopy and scanning electron microscope observations confirmed that soft rot, white rot and brown rot caused fungal decay in the pile. Tests on pulp quality showed that severe fungal attack at 1m height reduced fibre length to less than 2.0 mm compared to 3.8 mm for the control at both 1m and 4m height. Pulp yield loss of up to 12.0% was recorded amounting to about 40 ha of pulpwood going to waste per year. Statistical comparisons using the Duncan's Multiple Range Test indicated that strength values for paper specimens from the degraded chips were significantly lower than that of the control. Paper strength properties decreased substantially within six months with the tensile, tear and burst strengths decreasing by almost 17%, 19.0% and 14.0% respectively. Results indicate that the storage of pulpwood in multiple piles to reduce pile height and reduction in storage time to less than one month coupled with processing of chips on a "first in first out basis" can minimize the amount of degradation. They may be used as a basis for formulating control measures to minimize degradation at different chip heights. It is recommended that the firm adopt these storage practices, install porous material under each pile and construct drainage system to avoid retention of rainwater underneath the piles.
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Introduction

Panafrican Paper Mills manufacture various grades of paper from *Eucalyptus grandis, Cupressus lusitanica* and *Pinus patula* wood species. The wood Chips are stored in open air within the mill in two piles, one for the softwoods and the other as blended chips. Softwood chips in outside chip storage (OCS) are susceptible to severe biodegradation in warm climates (Wolfaardt and Rabie 2003; Ismail et al. 1989). Fungal attack on wood chips in storage has been reported to lower the pulp quality and yield (Zielinski, 1981; Ismail, Smith and Baecker, 1989). A pulp yield losses of 10% due to fungal attack and a subsequent impairment of tensile, tear and burst strengths of birch wood chips stored for one year in Sweden have been reported (Henningson, 1971). According to Asserson and Bergman (1971), *Chrysosphorium lignorum* fungi can lead to wood chip losses of about 11% per month in an outside chip storage.

Preliminary studies on the vertical and horizontal distribution of microbiological decay in both the softwood and hardwood chip piles at the mil showed that decay was present in the storage piles. A moisture content of 30.0% and temperature ranging between 25°C and 45°C were recorded in different parts of the pile. Such conditions are favourable for multiplication of fungi and degradation of wood chemical constituents especially cellulose which is the main component of wood pulp. Similar work done on Sweden showed that heat generated in chip pile could reach up to 70°C during summer (Zabel and Morrel, 1992, Eaton and Hale, 1993). A previous study based on cold pulping process using HaOH, indicated a decrease in pulp yield at the Paper Mill (Nyangiro, 1996).

The current pulpwood consumed by the Panafrican Paper Mills, the only mill in Kenya that produces paper from virgin pulp amounts to 38.000m^3 per annum. The consumption is projected to double by the year 2020 if the presented industrial development is sustained. Trends show that wood deficit in Kenya started from the year 2000 due to industrial development (KFMP, 1994). The trend can only be reversed through forest conservation and the minimization of wood degradation through appropriate methods based on effectiveness, low cost and acceptability to end-use (Suki, 2000; Smith

1975). Such a move is imperative to major wood consumers such as Paper mills. Softwoods become more susceptible to attack than hardwoods when the decay conditions are favourable (Zabel and Morrel, 1992). The losses caused by fungi in the softwood chip piles at Pan African Paper Mill have not been systematically quantified based on the pulping conditions at the mill. The objective of this study was therefore to determine wood losses as indicated by the change in pulp yield and quality in the *Pinus Potula* storage piles and identify the causative agents.

Materials and methods

Sampling Procedure

The study was carried out in the Pinus patula species storage pile. Sampling was carried out on monthly bases for six consecutive months. Specimens were stacked at points corresponding to the intersections of selected heights and horizontal distances. The chosen heights were 1m and 4m from the base of the pile while the horizontal distances were at 2m, 6m and 10m from the edge of the pile measured in both East-West and, North-South direction. Figure 1 illustrates the sampling layout with respect to the chip pile orientation at Panafrican Paper Mill.

Temperature at each point of collection was recorded during sampling using a mercury bulb thermometer. Immediately after collection, each specimen material was divided into three portions for microscopic examination, moisture content determination and pulp yield determination. The portion for moisture content determination was further divided into four and the mean moisture content of the four replicates recorded. Moisture content and temperature values were tabulated with respect to sampling points to indicate the microenvironment conditions within the pile.

Examination of chips

Light microscopic examination

Light microscopy was used to categorize different attacks by the wood degrading fungi. Sections of about 20 µm were cut from each sample chips using a microtome. They were stained with fast green solution. Temporary slides were prepared by mounting the sections on glass slides and covering them with cover slips. The amount and type of fungal degradation were determined through initial observations of the sections under a light microscope. The sections were then dehydrated with alcohol at concentrations of 50%, 85% and 100% and any excess alcohol in the wood cells removed using cyclone. Permanent slides were prepared by mounting the sections using DPX mountant and drying in an oven at 50° C for 30 minutes. The permanent slides were used in the photo microscopic examination of different forms of decay involved.

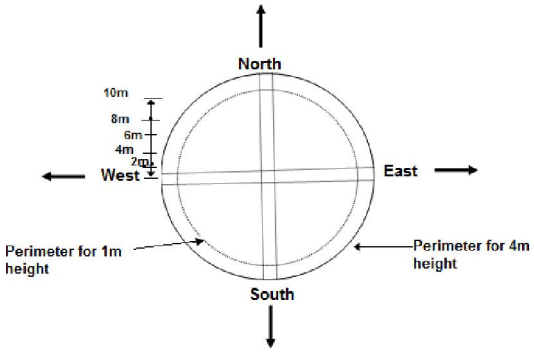

Figure 1: Sampling Layout.

Scanning electron microscope examination

The decayed chips were immersed into canopy's fluid immediately after sampling, to fix the wood cells. Sections of about 20µm were cut from these samples using a microtome. And dehydrated with ethanol at concentrations of 50%, 70%, 90%, 96% and 100%. This process was repeated three times with the sections shaken in a rotary shaker for 40 minutes for each of the concentrations to facilitate dehydration. Successive changes of xylene at concentrations 50%, 85% and 100% were used to remove the alcohol form the wood cells with samples retained for 40 minutes in each concentration. After the last change of the absolute (100%) xylene, the sections were air dried for 40 minutes, mounted ones tubs and then gold coated for 30 minutes. These were examined on a scanning electron microscope, model Jeol Jsm T33A with the magnification varied appropriately to reveal the extent of wood degradation.

Determination of pulp yield

On kilogram of oven-dry chips from each sample was introduced into a pilot plant digester at a wood dry weight to fluids ration of 1:4. The fluids included cooking liquor and water. For each sample, 2.15 liters of white liquor (HaoH, $NaSO_4$, Na_2S and $NaCO_3$) and a predetermined amount of tap whose volume was dependent on the moisture content of the chips were introduced. The analysis of the white liquor used was as follows:-

Total titratable Alkali (T.T.A): 101.0 - 106.0 g/1

Initial concentration of the active alkali (:90.5-95.0 g/1)

Percentage chemical (NaS2 and NaOH): 16 - 18%

Percent sulphidity: 24 - 27%

Electrical current was regulated manually to control the heating rate of the pilot plant digester.

Each sample was cooked for 2 hours and 45 minutes with the cooking temperature raised to 168°C and a pressure of 6.5 bars within the first 90 minutes. The temperature was maintained constant for 75 minutes to allow digestion. After each cooking, the pulp was washed with tap water on a 100-mesh wire, squeezed gently to remove excess water then air-dried separately to a constant weight. Several ten-gram samples of the air-dried pulp wetter oven dried at a temperature of 105°C for 48 hours to determine the moisture content. The moisture content was used to determine the oven dry weight of the pulp as a measure of pulp yield from each sample. The pulp yield from each control samples were taken to be 100%.

Pulp yield loss was calculated as follows:

$$\text{Pulpyieldloss}(\%) = \frac{Pulpyield(sample)}{Pulpyield(control)} \times 100$$

Determination of Pulp Quality

After determining the pulp yield, the pulp from each sample was mixed with water by running it in a laboratory valley beater to a uniform consistency of 1.6%. The pulp freeness was determined before beating (time 0)) and after beating for 40 minutes using the Canadian freeness tester. The volume of water collected from each sample was converted to equivalence in degree Shopper Reighler (°SR) from the conversion table and tabulated according to the sampling position.

Testing of paper Quality

From each sample,, 187ml of the pulp at a consistency of 1.6% were used to make 10 standard hand sheets weighting 120 g/m^2 using the hand sheet-forming machine. The following tests were carried out on four replicates and the mean value recorded.

Tensile Strength

Several 15 mm wide by 100 mm in long specimens were prepared from the dry hand sheets according to TAPPI standards T231 and T481 and tested in tension using Enrico Toniolo tensile tester.

Tear Strength

Several 50 mm by 50 mm specimens were prepared from the dry hand sheets according to TAPPI standards T414 and their tear strength determined using Elmendorf paper tear tester.

Burst Strength

A number of full-size hand sheet papers were used for this test. Their bursting strength was determined using Monitor burst strength tester, according to TAPPI standard T403.

Results and discussion

Visual observation showed that sampled collected at 1m above ground were darker in colour than those collected at 4m above the ground an indication of fungal colonization. Light microscopy and scanning electron microscope observations confirmed that fungal decay in chip pile was caused by soft rot, white rot and brown rot fungi.

The incidence of decay was more severe at 1m than 4 m height above the ground. This can be attributed to chips collection procedure during processing. The bulldozer that pushes chips to the turntable avoids picking the chips from low levels, as they are known to contain foreign particles such as soil. Hence this leaves the chips at this level undisturbed for even up to 8 months.

During storage period, heat increased in some parts of the pile especially where the chips remain undisturbed for a long time reaching about 70°C. These findings are in agreement with observations by Eaton and Hale (1993) who established that internal temperature changes in the pile are affected by the size of chips and the amount of sawdust that creates good insulation in certain parts of the pile. Besides there is heat release due to respiration by living sapwood cells, as well as oxidation reactions in the cell wall components. Micro-ecology is temperature-dependent and fluctuations in temperature within pile results in a change in microbial population. A stable temperature pocket may sustain a group of microorganisms, which prevail throughout the storage period (Easton and Hale, 1993; Zilienski, 1981).

Moisture content in wood can be used as a measure of microenvironment requirement for fungal decay to occur. The moisture content in the Panafrican Paper Mill chip pile at the two sampling heights ranged between 30.0% and 60.0% with higher amounts at the lower level making more conducive to fungal degradation. High moisture content at lower level may have been due to mass transfer phenomenon whereby water trickles done by gravity to the base of the pile. The moisture accumulates due to low evaporation rate and poor porosity of the highly compacted solid made of wood-dust that has settled at the ground level. According to Nicholas (1973), fungal decay depends on temperature and moisture, a fact that is consistent with the findings of Pan African Paper Mills. The high levels of attack are attributed to the favourable environmental conditions in the chip piles and poor operations at the chipper house.

Wood decay did not show any dependency on the orientation of chip pile with respect to the geographical directions followed during sampling. This is mainly due to non-directional wind flow in the open yard that contributes to an even distribution of temperature and moisture within the pile. Pulp yield at both heights was significantly lower than for

control after one month of storage. Results also show that pulp yield decreased with storage time, as shown in Figure 2. Fibre classification results (Table 1) show that there were a large proportion of short fibers at the ground level where the severity of fungal attack was high. The fibre length was greatly reduced in the midpoints between the conveyor belt and the pile circumference (6m and 14m) for both vertical heights.

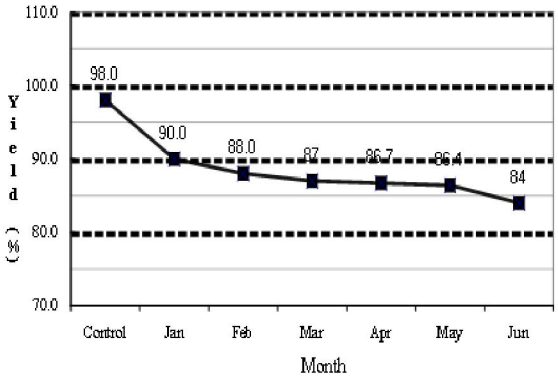

Figure 2: Variation in pulp yield with storage time.

Also the prorogation of fibres less than 0.2 mm long was highest at the same points for both sampling directions with a corresponding low pulp yield at the ground level. Short fibres may have been washed away during the washing process of pulp hence low yields at these points with severe fungal attack. This was probably due to increase in fungal colonization causing continuous degradation of chips. Similar studies (Ferraz et al, 2002) indicated that cellulose is depolymerized by *Cerioporiopsis subvermispora*.

Pulp yield loss of upto 12.0% was recorded corresponding to the pulp obtainable from about 120m^3 of wood daily with an equivalent market value of about Kshs.17.3 million per year. Cumulatively, this loss can be interpreted to about 40 ha of pulpwood going to waste every year due to fungal degradation. It is estimated non-commercial thinning contribute about 8.0% wastage of the forest plantations for pines and cypress (Chikamai and Ndegwa, 1997), logging wastes account for 24.0% of harvested wood volume while saw dust takes about 15.0% of sawn wood (Chikamai and Ndegwa, 1997) in Kenya. Such wastage and its impact on forest resource decline as can be avoided if biodeteriration of wood chips in storage piles is controlled by application of proper chipper house operations or by preservative treatment.

Pulp freeness for the samples collected and 1m above the ground was generally lower than all the other samples including the control. Low freeness indicates that the pulp has higher ratio of short to long fibers as confirmed by the fiber classification results shown in Table 1. Pulp with high ratio of short fibres produce papers of low strength properties.

Table 1: Pulp freeness

Pile height (m)	Distance from pile periphery(m)									
	Control	2	4	6	8	10	8	6	4	2
1	3.60	2.03	2.20	2.25	2.32	2.70	2.29	2.32	2.19	1.93
4	3.80	2.88	3.20	3.47	3.56	2.70	3.59	3.49	3.15	3.00

The highly significant difference between the control and the samples collected at 1m and 4m at horizontal distances of 4m and 8m shows that the high ratio of short fibres was directly related to the fungal attack.

It was observed that the pulp freeness increased with strorage time as illustrated in Figure 3**.** This trend is attributed to the severity of fungal attack and accompanying reduction the size of fibreas into fines. Other resutls (Akhtar et al, 1993) have shown that treatment with white-rot fungus leads to extensive fibrillation of fibreas and improved paper properties when the attack is not excessive.

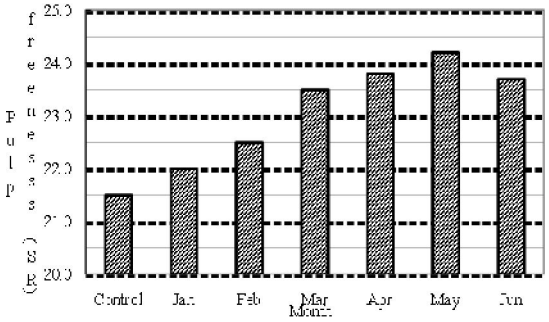

Figure 3: Variation in pulp freeness with time.

Pulp from samples that were highly attacked at 1m above the ground, exhibited significantly reduced freeness from the control after beating for 40 minutes. Pulp beating has the effect of defibrilising wood fibres to improve the bonding properites during paper formation. The high propriation fo short fibres could be attributed to weakenss amongst the fibres due to the fungal attack and further reduciton into shorter fibres or fines during beating. Samples not severely attacked, did not differ significantly from the cotrol after beating because the fibres remained relaitvely intact and strong. Wood decay fungi have the ability to hydrolyze the cell wall compoents reducing the cellulose chains and the fibre length and strenth (Nicholas, 1973, Hunt et al., 2002).

Tensile strength varied from 5.31 to 6.10 kg/cm, compared to 6.85 kg/cm for the control from fresh wood pulp, representing a reduction of 17.0%. the tensile strength decreased with storage time. The

increased fungal colonization and decay with stroage time produced pulp with short fibres leading to a reduciton in tnesile strength. This is a result of poor bonding between the fibres and paper formaiton characterics that are governned by the quality of the fibres, the contact area and the degree of beating for additive-free pulp. The poor paper formation was due to numerous joints of these short fibers that formed weak points. Fungal attack reduces the available hydroxyl groups available for bonidng and the nubmer of linkages along the fibre length making it easier to separate overlapping fibres by pulling as in tension. Besides, cellulose is depolymerized to an extent after a months fungal pretreatment (Ferraz et al, 2002) a fact that correlates well with the observed results.

Tear strength varied from 14.2 to 18.0 N/cm compared to 21.50 N/cm for the cotnrol equivalent to a 19.0% reduction. The strength decreased with storage time as illurstrated in Figure 4.

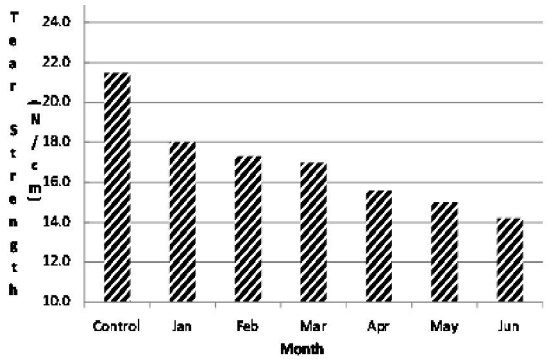

Figure 4: Variation in shear strength with time.

Pulp from the chips attacked by fungi, contained short fibres and probably different physical structures due to decay. In addtion to reduction in the available hydroxyl groups available for bonding hence the nubemr of cross-linkdages, the shrot fibres give rise to numerous joints in machine direction. Consequently, paper made from the decayed chips could easily be torn across exhibiting lower tear strength than that form fresh chips. This can be attributed to reduced fibre bonding capaicy resulting from change in chemcial state (Zanuttinni and Marzorchi, 2003).

Burst strength decreased with storage time as shown in Figure 5. Burst strength of paper is dependent on bonding strength among the interlocking fibres.

Burst strenth varied from 3.16 to 4.17 kg/cm^2, a 14.0% reduction over that of cotnrol. Pulp from the degraded chips had short fibres and poor paper formation characteristics. The combined reduction in bonding sites due to fungal attack and formation of numerous joints across machine direction made paper from decayed chips easy to rupture. This is attributed to areas of weakenss acorss and along the fibre axis contiruted by numerous joints and reduced surface areas respectively. Further, this may be contributed by the decrease in degree of polymerizaiton and crystallinity arising from advanced fungal attack (Gazdaru et al., 1999). The paper from fresh chips exhibited higher burst strength because of the resistance to severance of fibres acorss the length. Dependancy of the strength properites on fibre length points to a strong correlation between the proeprities and fibre length recuction. However, some studies (leatham et al., 1990; Sithole et al., 1999) have indicated that short term (four week) white-rot fungal attack leads to increased strength and optical properties. Statistircal correlations can be determined after a maore extensive testing of the strength parameters.

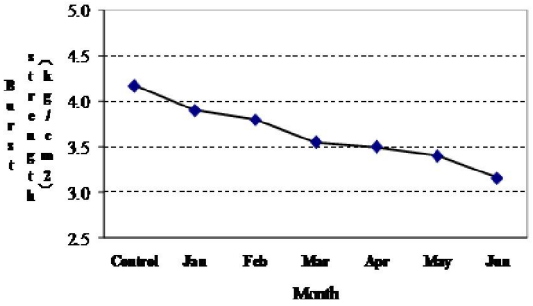

Figure 5: variation in burst strength with time.

Conclusion

Fungal distribution in the stroage pile at Panafrican Paper Mills, Webuye was dependent on temperature and moisture. The fungal attack was generally high at the ground level where the chips remained undisturbed for up to about 8 months before the pile was cleared. The paper strength properties namely tensile, tear and burst strength decreased by 17.0%, 19.0%, 14.% respectively. This was as a result of recuction of fibre length by fugnal decay that increased with stroage time especially at the ground level and at short periods of one month. It is recommended that the management employes methods that could be sued to effect tuilizaiton fo wood chips on a “first in first out system” and recuce storage period to less than one month. Biodeterioration of wood chips in the *Pinus patula* storage pile at the mill causes upto 12% loss in pulp yield. This loss is significant in Kenyan standards given the fast depletion of forest resoruces. Employing proper storage and processing methods can minimize such losses.

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