The Impact of Log Moisture Content on Chip Size Distribution When Processing Eucalyptus Pulpwood

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Chip moisture content and especially its uniformity impact kraft pulping. However, the effect of pulp log moisture content on chip quality during chip production is not well known. Chip size distribution is important in kraft pulping as it impacts chemical use, pulp quality and recovery. This study investigated the influence of two pulp log drying periods (1 and 2 weeks) on chip moisture content and chip size distribution when chipping eucalypt pulp logs. In addition, the effect of three log classes (base, middle and top logs) on chip moisture content and chip size distribution were also analysed. Within the respective log classes, moisture content of chips produced from logs dried for 2 weeks was 5.5% to 13.2% lower than moisture content of chips produced from logs dried for 1 week. Chip moisture content also decreased with decreasing log size for both log drying periods. One week dried logs produced chips with 1.0% less over-thick chips than 2 week dried logs (1.5% versus 2.5%). One week dried logs also produced chips with 4.2% to 7.2% less accepts than chips produced from 2 week dried logs within respective log classes. Across both drying periods, over-thick chip production increased with decreasing log size, while the amount of accepts produced decreased with decreasing log size. Logs dried for 2 weeks produced chips with significantly less under-sized chips than logs dried for 1 week. Two week dried logs produced chips with 4.4% to 7.7% less pins and 0.7% to 1.0% less fines than 1 week dried logs within respective log classes. For both log drying periods, the amount of under-sized chips produced increased with decreasing log size.

Keywords: Pulp logs, eucalyptus, moisture content, chip size

1. Introduction

Commercial forestry is practiced on 1.273 million ha or 1.1% of South Africa's total surface area. South African commercial forests serve various wood based industries, of which the pulp and paper industry is the largest (FES 2011). During 2011, the industry produced a total 18.5 million m^3 of roundwood, of which 12.6 million m^3 was harvested for pulp and paper production. Revenue for these pulp log sales amounted to EUR 279 million and pulp product sales from primary processing plants was EUR 799 million (FSA 2013). Fast growing eucalypt hardwood species supply 83% of wood resources used for pulp and paper manufacturing (FES 2011).

Pulp logs are purchased and harvested on a per green tonne basis. Therefore, the moisture content of pulp logs at the time of purchase has a significant impact on the pulp log price as it influences wood mass. Previous studies have investigated the impact of log moisture on chip size distribution, when producing chips for the bioenergy market (Spinelli et al. 2011, Mihelič et al. 2015). However, little is known on how log moisture content or log drying period length influence wood chip quality (i.e. thickness, size distribution and chip fracturing) during chip production, when producing chips from eucalypt pulp logs in a plantation setting. Chip quality is important as it influences pulp recovery and quality in kraft pulping (True 2006, Macleod 2007, Gulsöy 2012).

Pulp log (from here on referred to as log) moisture content (MC) influences mechanical wood properties such as wood hardness, strength and processing ability (Niedźwiecki 2011). Physical log properties such as log size (length and diameter), degree of debarking, log surface damage and wood density influence the rate of moisture loss. Logs with bark experience slower moisture loss as opposed to debarked logs or tree sections

(Connel 2003, Röser et al. 2011). Sapwood is more exposed to climatic elements after debarking and, therefore, has higher moisture loss rates when compared to heartwood (Defo and Brunette 2007, Färlin 2008).

Freshly harvested logs lose moisture while in storage either in the plantation, at roadside or at the mill (Röser et al. 2011). Various storage practices such as stack geometry, orientation to sun and wind, locality and individual log exposure will either accelerate or inhibit the rate of log drying (Persson et al. 2002, Defo and Brunette 2007, Färlin 2008, Gjerdrum and Salin 2009, Phanphanich and Mani 2009, Röser et al. 2011, Eisenbies et al. 2014, Erber et al. 2014, Routa et al. 2015). Smaller log stacks dry quicker due to higher log surface exposure and log stacks sheltered from the wind and sun will have slower drying rates (Persson et al. 2002, Defo and Brunette 2007, Färlin 2008).

Seasonal variations in temperature, precipitation, relative humidity, wind speed and wind direction will influence log drying rates (Gjerdrum and Salin 2009, Defo and Brunette 2007, Röser et al. 2011). Log moisture loss is greater at higher ambient temperatures, low atmospheric humidity and/or when logs are exposed to a prevailing wind (Persson et al. 2002, Connel 2003, Defo and Brunette 2007, Gjerdrum and Salin 2009, Röser et al. 2011). Precipitation replenishes log moisture and will reduce moisture loss (Defo and Brunette 2007, Gjerdrum and Salin 2009, Röser et al. 2011).

Processing efficiencies and pulp yield can be directly related to chip quality, as chip quality plays an important role in pulp recovery (MacLeod 2007). Chip moisture content, and especially uniformity, have a major impact on the kraft pulping process (Pulkki 1991). The quality of chips derived from chippers is expressed in terms of chips size distribution: i.e., the percentage of accepted chips (prime and small-size chips), over-size chips, over-thick chips, pins and fines, and whether the chips contain any impurities in the form of bark, knots and rot. In kraft pulping, chemical penetration times vary in relation to chip size, thickness and uniformity. Uniform chips lead to more uniform pulping conditions and higher pulp recovery (Pulkki 1991, Twaddle and Watson 1992a, Twaddle and Watson 1992b, Twaddle and Watson 1992c, MacLeod et al. 1995, Uhmeier 1995, Hartler 1996, Uhmeier and Persson 1997, Broderick et al. 1998, Tessier et al. 1999, Bjurulf 2005, Ding et al. 2005, Bjurulf 2006, True 2006, MacLeod 2007, Balakrishnan 2008, Färlin 2008, Santos et al. 2008, Hellström 2010, Walton et al. 2010, Mafia et al. 2012, Patt et al. 2012).

Timber freshness is expressed in terms of the MC in the wood itself and will influence chip size distributions during chip production (Qian et al. 1994, Hellström 2008, Hellström 2010, Isokangas 2010, Niedźwiecki 2011). An increase in chip thickness during chip production has been observed, with decreasing log MC. When log MC is very high or low, chip size and uniformity will be negatively affected. Logs with very low MC produce greater quantities of undesirable small chips (fines and pins) and large chips (over-sized and over-thick chips) due to decreasing wood plasticity. At higher MC, the wood is softer and greater quantities of pins and fines are produced (Pulkki 1991, Uhmeier and Persson 1997, Persson et al. 2002, Bjurulf 2006, Watson and Stevenson 2007, Färlin 2008, Hellström 2008, Niedźwiecki 2011, Mihelič et al. 2015). No studies could be found to indicate optimal MC for chipping as wood processing is a function of the interactions between wood density and MC (Niedźwiecki 2011).

Watson and Stevenson (2007) investigated the influence of seasonal variations in log MC of softwood and hardwood species on chip size and uniformity and their effect on kraft pulping. The authors found that over-sized chip production increased with decreasing seasonal log MC. While as MC increased, under-sized chips production increased.

No literature was found as to how log MC influence size and uniformity of eucalypt chips, nor have critical log moisture values been associated with eucalypt chip quality.

The objective of the study was to determine the influence of two log drying periods and three log size classes on the quality of chips produced in relation to chip size distribution, including any fracturing, chip MC and chip uniformity.

2. Materials and methods

2.1 Site selection, treatments and harvesting

The study was done near Kwambonambi in the Northern KwaZulu-Natal forestry region of South Africa. The coastal region is subject to sub-tropical climates, with mean annual temperature and precipita-

Table 1 Study site and tree details

Species	E. grandis x urophylla
Age, years	8
Establishment spacing, m	3x2.5
SI	26.20
MAI (6 years), m^3 ha^{-1} yr^{-1}	31.4
DBH, cm	15–20
Slope, %	<2

tion of 22°C and 1196 mm, respectively (Dovey 2012). An even-aged *Eucalyptus grandis*×*urophylla* cloned compartment of relatively uniform tree size was selected for the study (Table 1). The trees were harvested during spring, September 2012, when eucalyptus sapflow has been observed to be high in the Kwambonambi area (Dye et al. 2004).

Size distribution and MC of chips produced from logs dried over 2 drying periods were compared. This includes drying period 1 – as fresh as possible (in this case 1 week drying); and period 2 – two weeks of drying before chipping was initiated.

In addition, a distinction was made between 3 log size classes and it was taken into account how class related to chip size distribution and uniformity with log drying period. Three logs were removed from every tree (base, middle and top logs). The top log was the third log up the tree, but was not necessarily the last possible log available from any specific tree.

For this study, 120 trees were felled in harvester settings with a single grip harvester with up to 5 feed roller passes along the log surface. A harvester setting comprised of 10 trees (5 rows wide and 2 rows deep), and 60 trees were allocated to each of the log drying treatment. Log drying periods were randomly assigned within the experimental design. Trees within each setting were colour coded according to log drying period and tree position. Each tree was also sequentially numbered.

From each of the 120 tree, three 5.5 m logs were processed: one from the base, one from the middle and one from the top of the tree. The study produced 360 individual logs. There were equal numbers of logs for each of the log classes (base, middle and top logs). Trees with growth deformities, such as double leaders and butt sweep, within the experimental layout were excluded and formed part of the buffer zones to maintain design continuity.

A SP Maskiner 591LX harvesting head mounted on a tracked Hitachi IS200 excavator base was used for the study. The feed roller pressures were pre-calibrated for tree size (DBH) and the particular bark characteristics (thickness and adherence to the stem) to minimise potential log surface damage induced by the feed roller before the study commenced.

A Timberpro TF840-B forwarder extracted and loaded the log assortments directly onto a timber truck. The load was securely covered with a tarpaulin to limit moisture loss during transport to the chipping facility.

Logs were chipped in a Bandit 250 XP mobile disc chipper. Chipper maintenance was done by a chipper technician prior to chipping. Chipper maintenance included knife change and anvil clearance adjustments. The chipper knife angles were fixed at 45°.

Logs were separated and stacked according to the drying period which they would be subjected to. When the logs reached the predetermined drying period, chipping was initiated. The logs were manually fed into the chipper to avoid potential grapple induced log surface damage from the mechanical loader. The chips were ejected from the chipper spout by means of the standard blower into an industrial tumbler. The tumbler container opening was covered by plastic bags, to prevent any chips from escaping the container. Chips produced from individual logs were mixed thoroughly in the tumbler for one minute before a 12l sample was extracted. Samples were immediately placed in plastic bags and sealed to avoid further moisture loss. Each log tag information was copied onto the bag containing the chips produced from it. The remaining chips were discarded.

The green mass of each sample was recorded before being repacked into brown paper bags to facilitate moisture loss while in storage. Individual log information was replicated onto the paper bag. Samples were stored off the ground for 1 month to allow for air drying.

Subsequently, the chip samples were screened for 5 min according to SCAN-CM 40:94 standards into 5 chip size classes (over-sized, over-thick, accepted, pins and fines) using a mechanical chip size screener (SCAN-Test 1994). Each of the 1800 individual fractioned chip class sub-samples (5 chip class sub-samples per chip sample), were marked for identification and bagged separately. Chip class sub-samples were dried at a temperature of 105°C for 24 h according to SCAN-CM 39:94 standards to determine dry matter content. Individual chip class sub-samples were expressed as a mass percentage of the total sample bone dry mass (SCAN-Test 1994).

Chip MC was calculated for individual samples according to D4442-07 standards for the direct moisture content measurement of wood and wood-base materials (ASTM International 2007).

2.2 Statistics

Two way multi factorial analysis of variance (ANOVA) was used to analyse the data using the STATISTICA 10 software package (StatSoft 2012). The null hypothesis tested was for no treatment interaction effect. If the null hypothesis was rejected, individual treatment effects were compared. However if the null hypothesis was not rejected, treatment interactions are significant and only the interactions between treatments were analysed, as treatment effects were dependent of each other (Milton and Arnold 1999). When significant differences were found between treatments or treatment interaction effects (α=0.05), significant differences between individual means were determined using a post hoc Bonferroni *t*-test, as ANOVA residuals were normally distributed. The least square means (LSM) method was used for the representation of significant treatment interactions.

3. Results

3.1 Chip moisture content

The interaction between log drying period and log class had a significant effect on wood chip MC ($p<0.001$), Table 2.

Two week dried top logs with a MC of 31.8% produced chips 12.1% lower in MC than chips produced from two week dried base logs (31.8% versus 43.9%) and 6.2% lower in MC than chips produced from two week dried middle logs (31.8% versus 38.1%). Two week dried top logs also produced chips 17.6% lower in MC than chips produced from one week dried base logs (31.8% versus 49.4%), 16.1% lower in MC than chips produced from one week dried middle logs (31.8% versus 47.9%) and 13.1% lower in MC than one week dried top logs (31.8% versus 45.0%). Two week dried middle logs with a MC of 38.1% produced chips 5.9% lower in MC than two week dried base logs (38.1% versus 43.9%). Two week dried middle logs also produced chips 11.3% lower in MC than one week dried base logs (38.1% versus 49.4%), 9.9% lower in MC than one week dried middle logs (38.1% versus 47.9%) and 6.9% lower in MC than one week dried top logs (38.1% versus 45.0%). Two week dried base logs with a MC of 43.9% produced chips 5.5% lower in MC than one week dried base logs (43.9% versus 49.4%) and 4.0% lower in MC than one week dried middle logs (43.9% versus 47.9%).

One week dried top logs with a MC of 45.0% produced chips 4.4% lower in MC than one week dried base logs (45.0% versus 49.4%) and 2.9% lower in MC than one week dried top logs (45.0% versus 47.9%). One week dried middle logs with a MC of 47.9% produced chips 1.5% lower in MC than one week dried base logs (47.9% versus 49.4%).

Table 2 Effect of log drying period and log class on chip MC

Log drying period	Log class	MC, %
1 week	Base	49.4±0.31[e]
	Middle	47.9±0.32[d]
	Top	45.0±0.30[c]
2 weeks	Base	43.9±0.24[c]
	Middle	38.1±0.27[b]
	Top	31.8±0.38[a]

3.2 Chip size distribution

Chip size and uniformity differed significantly in relation to log drying period (Table 3), log class (Table 4) and the interaction between the treatments (Table 5).

Table 3 Means table for over-size chips, over-thick chips, accept chips, pin chips and fines produced from logs subject to respective drying periods, expressed as a percentage

Log drying period	Chip size distribution, %				
	Over-size	Over-thick	Accepts	Pins	Fines
1 week	0.08±0.02	1.5±0.08[a]	74.2±0.36	20.8±0.30	3.5±0.044
2 weeks	0.15±0.04	2.5±0.10[b]	79.9±0.27	14.8±0.20	2.6±0.045

Table 4 Means table for over-size chips, over-thick chips, accept chips, pin chips and fines produced from respective log classes, expressed as a percentage

Log class	Chip size distribution, %				
	Over-size	Over-thick	Accepts	Pins	Fines
Base	0.09±0.03	1.6±0.09[a]	81.1±0.28	14.6±0.26	2.6±0.057
Middle	0.12±0.04	1.9±0.10[a]	77.1±0.34	17.9±0.33	3.0±0.053
Top	0.13±0.04	2.6±0.13[b]	72.9±0.43	20.9±0.42	3.5±0.061

Table 5 Means table for over-size chips, over-thick chips, accept chips, pin chips and fines produced for the interaction between log drying periods and log classes, expressed as a percentage

Log drying period	Log class	Chip size distribution, %				
		Over-size	Over-thick	Accepts	Pins	Fines
1 week	Base	0.05±0.02	1.0±0.10	79.0±0.31[d]	16.8±0.28[c]	3.1±0.062[c]
	Middle	0.13±0.06	1.3±0.10	74.3±0.37[b]	20.9±0.31[d]	3.4±0.050[d]
	Top	0.06±0.03	2.1±0.16	69.3±0.39[a]	24.7±0.32[e]	3.9±0.077[e]
2 weeks	Base	0.13±0.06	2.1±0.12	83.2±0.25[e]	12.4±0.19[a]	2.1±0.038[a]
	Middle	0.12±0.05	2.4±0.15	80.0±0.23[d]	14.9±0.21[b]	2.5±0.042[b]
	Top	0.20±0.08	3.1±0.20	76.5±0.40[c]	17.0±0.31[c]	3.2±0.072[c]

No significant interactions were observed between drying period and log class (p=0.370) and the amount of over-sized chips produced. The individual main effects of drying period and log class also had no significant effect on the amount of over-sized chips produced (p=0.085 and p=0.711), (Table 3, Table 4 and Table 5).

Main effect log drying period and log class had a significant effect on the amount of over-thick chips produced (p<0.001), (Table 3 and Table 4). One week dried logs produced 1.0% less over-thick chips than logs dried for two weeks (1.5% versus 2.5%). Base logs produced 1.0% less over-thick chips than top logs (1.6% versus 2.6%). Middle logs produced 0.7% less over-thick chips than top logs (1.9% versus 2.6%).

The interaction between log drying period and log class had a significant effect on amount of accepts produced (p<0.001), (Table 5). One week dried top logs produced 9.7% less accepts than one week dried base logs (69.3% versus 79.0%) and 5.0% less accepts than one week dried middle logs (69.3% versus 74.3%). One week dried top logs also produced 13.9% less accepts than two week dried base logs (69.3% versus 83.2%), 10.7% less accepts than two week dried middle logs (69.3% versus 80.0%) and 7.2% less accepts than two week dried top logs (69.3% versus 76.5%). One week dried middle logs produced 4.7% less accepts than one week dried base logs (74.3% versus 79.0%). One week dried middle logs also produced 9.0% less accepts than two week dried base logs (74.3% versus 83.2%), 5.7% less accepts than two week dried middle logs (74.3% versus 80.0%) and 2.2% less accepts than two week dried top logs (74.3% versus 76.5%). One week dried base logs produced 4.2% less accepts than two week dried base logs (79.0% versus 83.2%).

Two week dried top logs produced 6.7% less accepts than two week dried base logs (76.5% versus 83.2%) and 3.5% less accepts than two week dried middle logs (76.5% versus 80.0%). Two week dried top logs also produced 2.5% less accepts than one week dried base logs (76.5% versus 79.0%). Two week dried middle logs produced 3.2% less accepts than two week dried base logs (80.0% versus 83.2%).

The interaction between log drying period and log class had a significant effect on amount of pins produced (p<0.001), (Table 5). Two week dried base logs produced 2.5% less pins than two week dried middle logs (12.4% versus 14.9%) and 4.6% less pins than two week dried top logs (12.4% versus 17.0%). Two week dried base logs also produced 4.4% less pins than one week dried base logs (12.4% versus 16.8%), 8.4% less pins than one week dried middle logs (12.4% versus 20.9%) and 12.3% less pins than one week dried top logs (12.4% versus 24.7%). Two week dried middle logs produce 2.1% less pins than two week dried top logs (14.9% versus 17.0%). Two week dried middle logs also produce 1.9% less pins than one week dried base logs (14.9% versus 16.8%), 5.9% less pins than one week dried middle logs (14.9% versus 20.9%) and 9.8% less pins than one week dried top logs (14.9% versus 24.7%). Two week dried top logs produced 3.8% less pins than one week dried middle logs (17.0% versus 20.9%) and 7.7% less pins than one week dried top logs (17.0% versus 24.7%).

One week dried base logs produced 4.0% less pins than one week dried middle logs (16.8% versus 20.9%) and 7.9% less pins than one week dried top logs (16.8% versus 24.7%). One week dried middle logs produced 3.9% less pins than one week dried top logs (20.9% versus 24.7%).

The interaction between log drying period and log class had a significant effect on amount of fines produced (p=0.016), (Table 5). Two week dried base logs produced 0.4% less fines than two week dried middle logs (2.1% versus 2.5%) and 1.1% less fines than two week dried top logs (2.1% versus 3.2%). Two week dried base logs also produced 1.0% less fines than one week dried base logs (2.1% versus 3.1%), 1.3% less fines than one week dried middle logs (2.1% versus 3.4%) and 1.8% less fines than one week dried top logs (2.1% versus 3.9%). Two week dried middle logs produced 0.7% less fines than two week dried top logs (2.5% versus 3.2%). Two week dried middle logs also produced 0.6% less fines than one week dried base logs (2.5% versus 3.1%), 0.9% less fines than one week dried middle logs (2.5% versus 3.4%) and 1.3% less fines than one week dried top logs (2.5% versus 3.9%). Two week dried top logs produced 0.2% less fines than one week dried middle logs (3.2% versus 3.4%) and 0.7% less fines than one week dried top logs (3.2% versus 3.9%).

One week dried base logs produced 0.3% less fines than one week dried middle logs (3.1% versus 3.4%) and 0.8% less fines than one week dried top logs (3.1% versus 3.9%). One week dried middle logs produced 0.5% less fines than one week dried top logs (3.4% versus 3.9%).

4. Discussion

4.1 Moisture content

Previous studies have found that drying rates increased with decreasing logs size, hence the lowest chip MC was expected to be recorded for chips produced from the smaller top logs (Hartsough et al. 2000, Connel 2003, Defo and Brunette 2007).

Chip MC varied according to log drying period and log classes used for chip production. Differences in chip MC produced from the log classes were greater during the second week of drying (Table 2). For 2 week dried logs, the MC of chips produced from top logs was 6.3% lower than that of middle logs (31.8% vs. 38.1%) and chips produced from middle logs were 5.8% lower than base logs (38.1% vs. 43.9%). However, chips produced from 1 week dried top logs were 2.9% lower in MC than chips produced from middle logs (45.0% vs. 47.9%) and chips produced from middle logs were 1.5% lower in MC than chips produced from base logs (47.9% vs. 49.4%). The relatively low rate of moisture loss during the first week of drying was most likely due to the logs being protected by a tarpaulin for 6 days during the transport from the harvesting site to the chipping facility 1800 km to the south-west of the country (Persson et al. 2002, Gjerdrum and Salin 2009).

Differences in chip MC also gradually increased with decreasing log size when compared to chips produced from the different log section classes subjected to 1 and 2 week drying periods. Two week dried base logs produced chips 5.5% lower in MC than 1 week dried base logs (43.9% vs. 49.4%), 2 week dried middle logs produced chips 9.8% lower in MC than 1 week dried middle logs (38.1% vs. 47.9%) and 2 week dried top logs produced chips 13.2% lower in MC than 1 week dried top logs (31.8% vs. 45.0%).

4.2 Chip size distribution

The methodology developed for this study to investigate the influence of log drying period and log size on chip quality is unique. The method applied to separate chip fractions produced during chipping was sound in relation to the study objectives. However, an additional screen separating small sized accepts from prime sized accepts during screening would have been beneficial to better understand the trends observed regarding chip size distributions and the factors affecting them. Unfortunately, the necessary equipment was not available.

The main effects, as well as the interactions between the main effects, had no significant influence on over-size chip produced. Previous studies have shown that chips produced from horizontal feed disc chippers have significantly less over-size chips than chips produced from drop feed disc chippers (Twaddle and Watson 1992a, Twaddle and Watson 1992d, Nati et al. 2014). It has been found that logs fed into drop feed chippers have highly variable log orientations during chipping (Isokangas 2010). Logs from the thin ends of trees are often forced into chipping knives causing fracturing and even breakages due to uncontrolled log feeding speeds (Isokangas 2010). These factors could often lead to greater over-size chip production (Isokangas 2010).

Watson and Stevenson (2007) found that the amount of over-thick chips produced during chipping increased with decreasing log MC. One week dried logs produced chips with significantly less over-thick chips than 2 week dried logs (1.5% versus 2.5%).

Over-thick chip production also increased with a decreasing log size (Table 4). Base logs produced 1.0% less over-thick chips than top logs (1.6% versus 2.6%) and middle logs produced 0.7% less over-thick chips than top logs (1.9% versus 2.6%). Previous studies have suggested that the production of over-thick chips are related to wood quality defects such as irregular grain in wood and knots (Bjurulf 2006 and Cáceres et al. 2016). Knot content is a function of branch frequency and size (Malan 2003). For eucalypts, branch sizes increase with tree height (Dye et al. 2004, Kearney et al. 2007). Knot content will therefore proportionally increase with tree height and decrease with age, which would explain the greater production of over-thick chips for top logs (Dye et al. 2004, Kearney et al. 2007).

In addition, the interactions between drying period and log class had a significant effect on the percentage of accept chips produced (Table 5). One week dried logs produced chips with significantly less accept chips than 2 week dried logs. This trend was also observed within each log section class. One week dried top logs produced chips with 7.2% less accept chips than 2 week dried top logs (69.3% vs. 76.5%). One week dried middle logs produced chips with 5.7% less accept chips than 2 week dried middle logs (74.3% vs. 80.0%) and 1 week dried base logs produced chips with 4.2% less accept chips than 2 week dried base logs (79.0% vs. 83.2%). The percentage of accept chips produced during chipping is a function of the percentage of undesirable chip size fractions produced. As the percentage of under-sized and over-sized chip fractions increases, the proportion of accept chips correspondingly decreases.

Individual log sections also had a significant effect on the amount of accept chips produced during chip production. With decreasing log size, the percentage of accept chips produced decreased linearly. The trend was also observed for chips produced from logs dried for both 1 week and 2 week drying periods (Table 5). Comparing log sections dried for 1 week, it was found that top logs produced chips with 5.0% less accept chips than middle logs (69.3% vs. 74.3%) and middle logs produced chips with 4.7% less accept chips than base logs (74.3% vs. 79.0%).

Comparing log section classes dried for 2 weeks it was found that top logs produced chips with 3.5% less accept chips than middle logs (76.5% vs. 80.0%) and middle logs produced chips with 3.2% less accept chips than base logs (80.0% vs. 83.2%). The effect of wood MC on chip size and uniformity has been investigated internationally and it was shown that chips produced from logs with low or high MC produced greater amounts of non-optimum chips during chipping (Pulkki 1991, Uhmeier and Persson 1997, Watson and Stevenson 2007, Färlin 2008, Hellström 2010, Niedźwiecki 2011, Spinelli et al. 2011 and Mihelič et al. 2015). Surface wood dried quicker than sub-surface wood (Defo and Brunette 2007). With log surface to volume ratios increasing with decreasing log size, smaller logs have a larger portion of surface wood with greater drying rates leading to larger portions of excessively dry wood and lower proportions of accept chips produced (Bassler 1987, Pulkki 1991, Uhmeier and Persson 1997, Defo and Brunette 2007, Färlin 2008, Hellström 2008). After the 1 week drying period, the surface wood is dryer than the sub-surface wood, which then negatively affects accept chip production (Araki 2002, Defo and Brunette 2007, Watson and Stevenson 2007, Niedźwiecki 2011).

Interactions between the drying period and log class also had a significant effect on the amount of pins produced during chip production (Table 5). Two week dried logs produced chips with significantly less pins than 1 week dried logs. This trend was also observed within each log class. Two week dried base logs produced chips with 4.4% less pins chips than 1 week dried base logs (12.4% vs. 16.8%). Two week dried middle logs produced chips with 6.0% less pins than 1 week dried middle logs (14.9% vs. 20.9%) and 2 week dried top logs produced chips with 7.7% less pins than 1 week dried top logs (17.0% vs. 24.7%).

Moreover, log class had a significant effect on the amount of accept chips produced during chip production. With decreasing log size, the percentage of pins produced increased linearly. The trend was also observed for chips produced from logs dried for both 2 week and 1 week drying periods. Comparing log sections dried for 2 weeks, it was found that base logs produced chips with 2.5% less pins than middle logs (12.4% vs. 14.9%) and middle logs produced chips with 2.1% less pins than top logs (14.9% vs. 17.0%).

Comparing log sections dried for 1 week, it was found that base logs produced chips with 4.1% less pins than middle logs (16.8% vs. 20.9%) and middle logs produced chips with 3.8% less pins than top logs (20.9% vs. 24.7%). Wood MC has been found to have a significant impact on chip size and uniformity. Especially when wood moisture content was excessively high or low, the amount of non-optimum chips produced increased (Pulkki 1991, Uhmeier and Persson 1997, Watson and Stevenson 2007, Färlin 2008, Hellström 2010, Niedźwiecki 2011, Spinelli et al. 2011 and Mihelič et al. 2015). As previously mentioned, surface wood dried faster than sub-surface wood (Defo and Brunette 2007). As log surface to volume ratios increased with decreasing log size, smaller logs have larger portions of surface wood with greater drying rates that lead to larger portions of excessively dry wood and greater amounts of pins produced (Bassler 1987, Pulkki 1991, Uhmeier and Persson 1997, Defo and Brunette 2007, Färlin 2008, Hellström 2008). After the 1 week drying period, the surface wood is dryer than the sub-surface wood, which results to the production of greater quantities of pins (Araki 2002, Defo and Brunette 2007, Watson and Stevenson 2007, Niedźwiecki 2011).

Interactions between respective log drying periods and log classes had a significant effect on chip fines produced during chipping (Table 5). In fact, across all log classes, 2 week dried logs produced chips with significantly less fines than 1 week dried logs. Comparing fines content across the drying periods for individual log classes, the fines content difference increased with increasing log size. Two week dried base logs produced chips with 1.0% less fines than 1 week dried base logs (2.1% vs. 3.1%), 2 week dried middle logs produced chips with 0.9% less fines than 1 week dried middle logs (2.5% vs. 3.4%) and 2 week dried top logs produced chips with 0.7% less fines than 1 week dried top log classes (3.2% vs. 3.9%). A higher rate of moisture loss for smaller sized logs may explain why smaller sized logs have a smaller difference in the amount of fines produced, as smaller logs may be closer to optimum log MC for limiting fines production during chipping. It can be concluded that log MC has a significant effect on fines production (Bassler 1987, Araki 2002, Watson and Stevenson 2007, Niedźwiecki 2011).

Chip fines content also increased with decreasing log size for chips produced from logs dried for respective drying periods. One week dried base logs produced chips with 0.3% less fines than 1 week dried middle logs (3.1% vs. 3.4%) and 1 week dried middle logs produced chips with 0.5% less fines than 1 week dried top logs (3.4% vs. 3.9%).

Two week dried base logs produced chips with 0.4% less fines than 2 week dried middle logs (2.1% vs. 2.5%) and 2 week dried middle logs produced chips with 0.7% less fines than 2 week dried top logs (2.5% vs. 3.2%). Log surface to volume ratios increased exponentially as log size decreased; therefore, smaller log classes have greater proportions of exposed surface wood with low MC. Larger proportions of drier surface wood potentially led to greater quantities of chip fines during chip production (Araki 2002, Watson and Stevenson 2007, Niedźwiecki 2011).

5. Conclusion

A study to determine the impact of log drying period on wood chip size distributions was conducted. The study included 2 log drying periods with logs dried for 1 week and 2 weeks, respectively. In addition, the effect of log size on the production of chip size distributions was analysed. Trees included in the study were harvested during the relatively wet spring months in the Kwambonambi area in Northern KwaZulu-Natal of South Africa. The logs samples were chipped at a chipping facility located in the Western-Cape province of South Africa. The chip sample analysis was done at Stellenbosch University.

Results show that drying period and log size class had a significant impact on chip size fractions produced during chipping (over-thick chips, accepts, pins and fines). Drying period and log class had a significant effect on the amount of over-thick chips produced. One week dried log classes produced 1.0% less over-thick chips than 2 week dried log classes (1.5% vs. 2.5%). Over-thick chip production also increased with decreasing log size. Base logs produced 1.0% less over-thick chips than top logs (1.6% vs. 2.6%) and middle logs produced 0.7% less over-thick chips than top logs (1.9% vs. 2.6%).

In addition, the interaction between log drying period and log class had a significant effect on accept chip production. One week dried logs produced significantly less accept chips than 2 week dried logs across all log classes. One week dried base logs produced 4.2% less accepts than 2 week dried base logs (79.0% vs. 83.2%). Likewise, 1 week dried middle logs produced 5.7% less accepts than 2 week dried middle logs (74.3% vs. 80.0%) and 1 week dried top logs produced 7.2% less accepts than 1 week dried top logs (69.3% vs. 76.5%). Accept chip production also decreased with decreasing log size for logs subject to both log drying periods.

Moreover, results show that the interaction between log drying period and log class had a significant effect on the amount of pins produced during chipping. Two week dried logs produced significantly less pins than 1 week dried logs across all log classes. Two week dried base logs produced 4.4% less pins than 1 week dried base logs (12.4% vs. 16.8%). Meanwhile, 2 week dried middle logs produced 6.0% less pins than 1 week dried middle logs (14.9% vs. 20.9%) and 2 week dried top logs produced 7.7% less pins than 1 week dried top logs (17.0% vs. 24.7%). The production of pins also increased with decreasing log size for logs subject to both drying periods.

Finally, findings demonstrate that the interaction between log drying period and log class had a significant effect on chip fines production. Two week dried logs produced less fines when compared to 1 week dried logs. Further, 2 week dried base logs produced 1.0% less fines than 1 week dried base logs (2.1% vs. 3.1%). Meanwhile, 2 week dried middle logs produced 0.9% less fines than 1 week dried middle logs (2.5% versus 3.4%) and 2 week dried top logs produced 0.7% less fines than 1 week dried top logs (3.2% versus 3.9%). Fines production also increased with decreasing log size for both log drying periods.

6. Recommendations

Based on the results of this study, the following are the recommendations that forestry companies could follow in order to improve the quality of pulp logs used for pulp and paper manufacturing in relation to:

⇒ Debarking practices
⇒ Log MC
⇒ Tree size.

Log MC greatly influences chip size and uniformity during chip production. Infield log drying periods need to be adjusted according to climatic conditions, tree species and tree size. Log assortments extracted from individual trees during harvesting vary in size, and therefore will have a wide range of drying rates. Thus, log drying periods need to be suited to a variety of log assortments to ensure that log MC is as close as possible to the optimal MC for chip production. This is also essential to ensure uniformity in chip moisture content.

Additionally, it was found that tree size has a significant effect on chip quality. With decreasing log size, the amount of undesired chip fractions produced during chipping increased. As such, plantation compartments scheduled for annual harvesting operations should be revised to avoid the harvesting of undersized trees. Forestry companies should consider adjusting plantation felling ages to ensure larger tree size at the time of felling. Closer investigation is needed to determine the optimum tree size to facilitate debarking, and to maximize chip quality and pulp value recovery. Further research is also needed to determine the best MC range for chipping from a chip quality point of view.

Acknowledgments

Thanks and appreciation to Mondi Forests for the allocation of a study area and for financing the project. Thanks to Bandit South Africa for assistance in chipping operations.

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Received: February 05, 2016.
Accepted: March 18, 2016.

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