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RESEARCH ARTICLE

The contribution of Framed Chainsaw System to Improvement of Sawn Timber Quality

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ABSTRACT

In this study, the effect of framed chain sawing system with optimized chain on timber size uniformity and surface roughness was analyzed and compared with the freehand chainsaw system and band saw as control. The surface roughness of sawn timber from three commonly sawn timber species (*Eucalyptus saligna*, *Grevillea robusta* and *Prosopis juliflora*) was determined by stylus tracer approach. Freehand chainsaw produced timber with significantly the highest size deviation and surface roughness, while framed chainsaw using an optimized felling chain produced timber with more uniform sizes and smoother surfaces which did not significantly differ from that produced by a band saw. The findings of this study concluded that, the use of the frame on the chainsaw effectively control the chain to saw timber around the pre-set size thus producing timber with more uniform sizes. Modification of the cutters on the chain help in stabilizing the sawing speed, reducing the erratic behaviour of chainsaw, thus producing timber with smooth surface close to timber sawn using band saws. These parameters make framed chainsaw a choice eco-efficient small-scale timber sawing system, appropriate for timber sawyers operating on the farms, where trees are few, scattered and small in diameter.

INTRODUCTION

Dimensional consistency and surface quality are some of the most important properties of sawn timber. One way of determining the efficiency of a sawing system is by measuring its ability to saw timber consistently within specified thickness standards. Two basic factors that affect timber dimension accuracy include the human capability of determining the correct setting and the mechanical capability of the system to produce timber within given tolerances (Reineke, 1966). Although all mills must include a plus or minus tolerance around their target size to allow for this variation in lumber thickness, the amount of tolerance required for a dimension depends on stress in the logs, condition of sawing equipment, the manner in which it is operated and the target use for the timber (Reineke, 1966). With this tolerance included, it is expected that a good sawing system should maintain the size of the timber as close to the set dimensions as possible. A sawing system that produces timber with irregular size affects recovery due to under sized timber being rejected in the market while oversize timber has excess materials which can not be accounted for. This excess material has also to be removed through extra planning to reduce the thickness to the required dimension. Surface roughness is another important parameter to monitor in timber sawing. It is defined as the measure of the irregularities of a surface. The size and frequency of these irregularities establish the surface quality and defines how a surface feels, looks and works in contact with other surfaces (PDI, 1998). Sawn timber surface quality is of particular importance to secondary processing, especially furniture manufacturing, where the timber has to be subjected to planning to further improve the surface for a variety of purposes. Decreasing the roughness of timber surface usually increases manufacturing costs exponentially due to use of more sophisticated cutting tools and the subsequent maintenance costs. This often results in a trade-off between the manufacturing cost of timber and its performance in application. The level of roughness in timber surface is a factor of both the cutting tools used and the wood properties (Cassens 1991, Richter *et al.* 1995; Barbu *et al.* 2000). Wood natural properties (anatomical, physical, mechanical and even chemical) vary considerably, not only between different species, but even among trees in the same species and along the tree height (Chikamai, 1986). Wood anatomic structure causes a first-degree texture comprising of tracheid or vessel diameter and cell wall thickness. A second-degree texture results from the machining method used in processing timber, especially cutter marks and waves from saw cutters or planer knives.

Third-degree texture results from variation within the machining method resulting from vibrations due to misalignment and/or dull tools (Whitehouse, 1994). Irrespective of its cause, timber surface roughness is usually undesirable but difficult and expensive to eliminate. It can however be controlled through design, setting and operation of sawing equipment. Despite timber quality (size uniformity and surface roughness) being important properties for user applications, it is usually not a common practice for sawyers and timber users to assess it systematically. In most cases, visual observations are used to compare timber surfaces. Some studies investigated timber surface texture in relation to its influence on the performance of paints and glues (Muthike, 2003; Richter *et al*, 1995; Mutuku, 1981). However, no information was readily available characterizing timber surface texture with timber sawing systems.

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The purpose of this study was therefore to determine the effect of different sawing systems on timber quality (size uniformity and surface roughness).

MATERIALS AND METHODS

In the study, freehand chainsaw, commonly used for processing timber on farms and framed chainsaw with optimized cutters, which is an improvement of the freehand chainsaw system (Muthike *et al*, 2010) were compared to a standard band saw. Nine mature trees (three each of *Grevillea robusta*, *Eucalyptus saligna* and *Prosopis juliflora* species), which are the most commonly grown and sawn timber species on farms in Kenya were sampled, felled and from each butt section, a 2-m-long log with minimum knots and other imperfections cut. One such log from each species was sawn using freehand and frame guided chain saw systems with optimized felling chain. The third log from each species was sawn using a standard band saw, which in this study was used as a control. For all the sawing systems, through and through sawing pattern was used and 25-mm thick boards targeted. Three pieces of sawn timber from every log were randomly sampled. On each of these pieces, timber thickness was measured at the ends and at every 0.5m along the length. This data was used to compute the mean timber size deviation from the pre-set dimension. After determining the size deviations on the timber, each piece was cut into 300–mm long pieces and grouped together. Three pieces were randomly sampled from each group, obtaining a total of 81samples for surface roughness tracing. Before tracing, all specimens were conditioned to 12 percent equilibrium moisture content (EMC) in a room conditions (25°C and 65% relative humidity (RH)) for 14 days. Surface roughness, denoted as (R_a), is a quantitative calculation of the relative roughness of a linear profile or area, expressed as a single numeric parameter. Surface tracing equipments have been used and a roughness value either computed on a profile or on a surface. The profile roughness parameters (R_a and R_q) are more common (Whitehouse, 1994). In a surface represented as shown in figure 1, R_a and Rq are computed as in equations 1 and 2. R_a, is by far the most common, measured in micro-meters (µm) is determined as the mean of the other parameters (Östman, 1983).

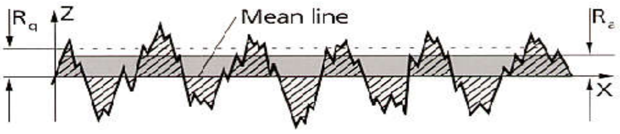

Figure 1. General material surface representation

$$R_a = \frac{1}{l}\int_0^l |Z(x)|\, dx \qquad (1)$$

$$R_q = \sqrt{\frac{1}{l}\int_0^l Z^2(x)\, dx} \qquad (2)$$

Surfaces of all the 81 specimens were traced using a commercial stylus tracing Perthometer S6P, (drive unit PRK of Feinprüf GmbH, 37008 Göttingen/Germany). This stylus tracing device is developed for quality control on work pieces with relatively smoother surfaces, such as metals and plastics. It was therefore necessary to calibrate the measurement range for the purpose of this study by elongating the length of the traverse (LT) and the vertical limit (VL) of the pickup to 5.6 mm and 250 µm respectively to scan rougher surfaces of wood. This was consistent with similar earlier studies where stylus tracing approach was used for wood surface roughness determination (Richter *et. al*, 1995; Funk *et al*, 1992). On each sample piece of timber, ten measurements were taken systematically all over the surface. Figure 1 shows a photograph and the schematic representation of the equipment used for the tracing process, while Table 1 shows its measurable characteristics.

Figure 1 (a). Stylus Roughness measurement equipment

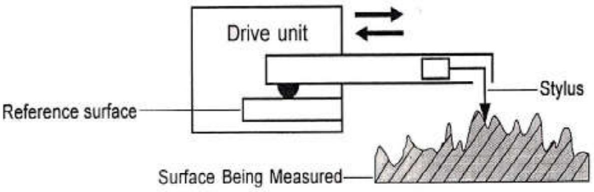

Figure 1 (b). Schematic Representation of the Stylus drive Unit showing the reference surface

Table 1. Characteristics of the stylus tracing

Characteristic	Measure
Tracing Direction	Across the grain
Tracing length	60mm
Tracing speed	0.5mm/sec
No. of measured points/traces	6,124
Pickup length	130mm
Stylus measurement range	Max 250 µm
Stylus tip radius	40µm
Force exerted on the surface	130mN

Because the number of data points measured per tracing unit on each piece was more than necessary (144 points/sample), the data sets were compressed by selecting only every sixth value per tracing unit. The result was a de-trended roughness profile representing 48 mm (reference length) of the tracing length per sample piece, yielding a total of 864 profiles. Three standardized roughness parameters: average roughness (R_a), average roughness depth (R_z), which measures the maximum vertical distances within the reference length and (R_t), which measures the maximum roughness depth of the valleys were measured. Two other parameters: peak roughness (P_r) and peak index (Pi) were derived from the obtained data and compared statistically (DIN 4768/ISO 4287), to find out if all the five parameters were correlated, to warrant a safe use of mean roughness (R_a) in the comparison.

Statistical Analysis

The five roughness parameters selected were compared statistically in a correlation analysis, manifesting a high correlation between all parameters (Table 2). The arithmetic mean (R_a) was therefore safely used in the comparative analysis. Data on size deviation and surface roughness was organized and analyzed separately. A two-way analysis of variance was carried out on all data to determine whether sawing system and wood species significantly influenced the timber size deviation and surface roughness. Differences between the means of independent variables were tested for significance using Tukey's Studentized Range Test at 5 percent probability level. All statistical analyses were performed with Gen-stat and SPSS software packages.

RESULTS

Size Deviation

On the overall, freehand chainsaw recorded a mean timber size deviation of +/- 5.53mm, which was significantly higher than the size deviations recorded for framed chainsaw (+/-2.44) and band saw (+/-2.16mm) (Table 2). Size deviations on timber sawn using framed chainsaw and band saw systems were not significantly different. Timber size deviations differed from species to species when sawn using the three sawing systems. Prosopis timber had the highest size deviation from the set dimensions (+/-5.99mm) when sawn using freehand chainsaw which differed significantly from deviations recorded for Grevillea (+/-5.33) and Eucalyptus (+/-5.26mm) for the same sawing system. The same species produced sawn timber with significantly differing size deviations among the other sawing systems. The latter two species produced timber which did not differ significantly. Figure 2 shows the distribution of the measured deviations from the set timber sizes for the three sawing systems. Freehand chainsaw had timber sizes varying widely from one another, with some of the measurements going below the set sizes. Framed chain and band saws had more or less similar variations of sizes with very low deviations compared to the freehand chainsaw. All timber sizes produced by these two sawing systems were higher than the set sizes.

Table 3 compares the residual errors obtained using timber size deviations for the three sawing systems and timber species. Residual error, ε, was defined as $\varepsilon(\%) = 100(\Psi_s - \Psi_a)/\Psi_a$, where Ψ_a and Ψ_s are the measured and pre-set timber sizes respectively. The mean and standard deviations of the residual errors were also computed. Freehand chainsaw had mean residual errors ranging from 3.4 – 15.3% with standard deviations varying from 3.7 to 14.4 for the three species of wood. The residual errors for the framed chainsaw were 4.6 -7.3% with standard deviations of between 0.6 and 0.7% for the respective wood species. Band saw system had residual errors of between 5.3 and 6.7%, with standard deviations between 0.5 and 1.3%. This shows that freehand chainsaw produced timber with a wider variation in sizes for all the species of wood than framed chainsaw and band saw whose timber sizes were more uniform. The results also show that, despite the deviations of the mean residual error from the desired value of zero, those for framed chainsaw and band saw systems were not significantly different except when Prosopis timber was sawn using band saw, whose mean residual error and standard deviation were significantly higher than the rest. Prosopis timber had more pronounced size deviations, which is highly associated to its high density, which would resist the saw cutters, causing increased vibration of the cutting tools, hence the deviations of the same from the set cutting lines. On the overall, framed chainsaw system produced timber with size uniformity close to that produced using the band saw system.

Table 2. Size deviation in timber sawn using different sawing systems

Sawing System	Timber Size Deviation (mm)			Mean
	Eucalyptus saligna	*Grevillea robusta*	*Prosopis juliflora*	
Freehand Chainsaw	5.26	5.33	5.99	5.53
Framed chainsaw	2.42	2.20	2.70	2.44
Band saw	2.14	1.96	2.38	2.16

p=0.05

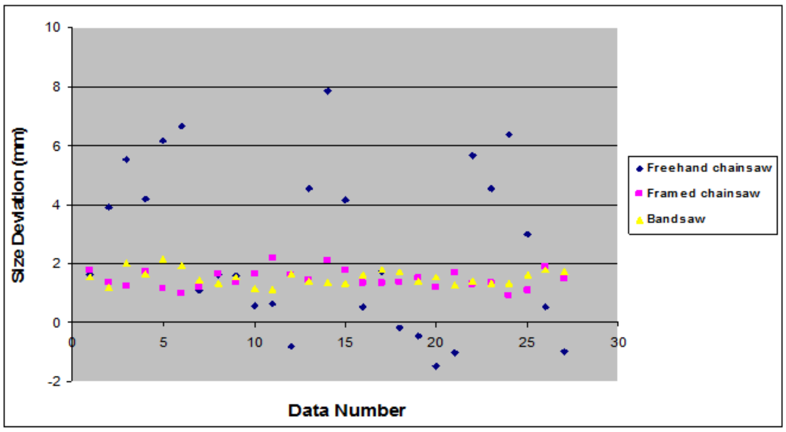

Figure 2. Distribution of measured deviations from the set timber sizes for three sawing systems

Table 3. Residual error (%) for size deviations in timber sawn using different sawing systems

Data No.	Freehand Chainsaw			Framed Chainsaw			Band saw		
	Euc	Grev	Pros	Euc	Grev	Pros	Euc	Grev	Pros
1	15.7	4.6	24.6	5.9	3.6	8.6	6.3	4.6	5.4
2	22.1	4.4	26.6	4.4	3.9	8.1	6.4	4.5	5.4
3	16.6	6.4	31.5	5.4	4.7	7.7	6.2	4.8	5.5
4	11.9	6.4	18.2	5.4	4.8	7.2	5.6	5.3	6.1
5	-6.0	2.2	2.6	5.2	5.0	7.0	5.3	5.4	8.4
6	11.2	-3.2	-0.7	5.9	5.5	7.2	6.4	5.6	8.7
7	18.2	-2.1	-0.18	6.9	5.3	7.0	6.2	5.6	6.8
8	22.7	7.0	-4.1	6.6	4.3	6.7	5.4	5.8	7.7
9	25.6	4.6	-3.8	5.5	4.1	6.6	5.6	6.4	6.7
Mean	15.3	3.4	11. 9	5.7	4.6	7.3	5.9	5.3	6.7
std	9. 4	3.7	14.4	0.7	0.6	0.7	0.5	0.6	1.3

*std = standard deviation

Roughness in Sawn Timber

Sawn timber surface roughness varied substantially for different sawing systems, among wood species and within the same piece. For ease of evaluation, the three measured and two derived roughness parameters were compared statistically in a correlation analysis manifesting a high correlation between all parameters (Table 2).

Table 2. Correlation coefficients between roughness parameters

	R_a	R_z	R_t	P_r	P_i
R_a	-	-	-	-	-
R_z	0.932	-	-	-	-
R_t	0.985	0.984	-	-	-
P_r	0.993	0.978	0.973	-	-
P_i	0.989	0.972	0.969	0.991	-

R_a =mean roughness; R_z =average roughness depth; R_t = maximum roughness depth; P_r = peak roughness; and P_i = peak index (n = 81, p = 0.05)

The highest and most homogeneous coefficients were found for R_a, which represents the arithmetic mean of the absolute values of the profile deviation. Because it is standardized in computation and the parameter is highly relied upon in other studies for roughness characterization (Richter *et. al*, 1995; Östman, B. 1983), R_a was therefore used in the analysis for ease of quantification and comparison of the timber surface roughness.

Effect of Sawing Systems on Timber Surface Roughness

Mean roughness **(**R_a) for all the profiles scanned in the study was plotted (Figure 1). Freehand chainsaw system produced timber with the highest values of R_a. Timber sawn using the framed chainsaw with optimized chain had lower mean roughness very close to that on timber sawn using the band saw (control). The Turkeys mean comparison procedure at 95% confidence proved that mean roughness of timber sawn using freehand (160.41±36.72 µm) was significantly different from the that in timber sawn using framed chain saw (105.34±12.75 µm) and the control (band saw) (95.10± 6.58 µm) with p = 0.00. Timber surfaces for timber sawn using framed chainsaw and band saw systems were however not significantly different (p = 0.13).

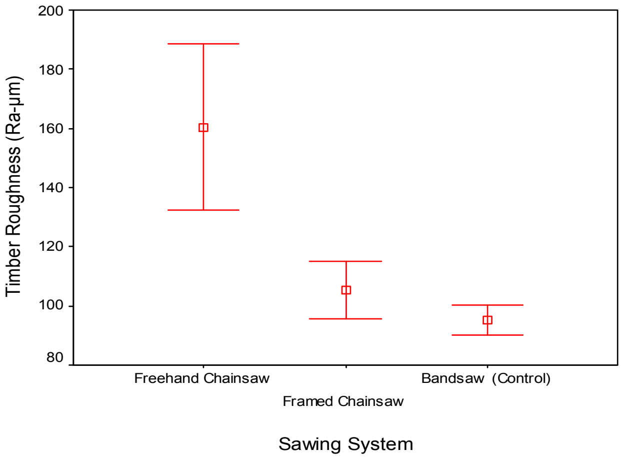

Figure 1. Mean values of average roughness (Ra) for three sawing systems.

It is also observed that freehand chainsaw system produced timber with both high roughness values (R_a) as well as higher standard deviations for all the wood species than both framed chainsaw and the control (band saw). This implies that timber sawn using this system varied in surface roughness more than that sawn using framed chainsaw and band saw. The standard deviation was lower for smoother samples where timber surfaces from framed chainsaw and band saw (control) systems showed a better homogeneity than timber surfaces from freehand chainsaw system.

Effect of Wood Species on Sawn Timber Surface Morphology

The effects of wood species on surface roughness are shown in Figure 2, where R_a values for the three species are depicted. There was a difference between surface roughness (R_a) between Prosopis and both Eucalyptus and Grevillea timber. The standard deviation was lower for smoother samples where timber surfaces from Eucalyptus and Grevillea wood showed a better homogeneity than surfaces of Prosopis wood. Turkeys mean comparison procedure at 95% confidence proved that mean roughness of timber from Prosopis wood (139.90±47.25µm) was significantly different from that from Eucalyptus (115.69±29.02 µm) (p = 0.001) and (105.27±23.35µm) (p =0.000). Surface roughness for timber from Eucalyptus and Grevillea did not differ significantly (p = 0.124).

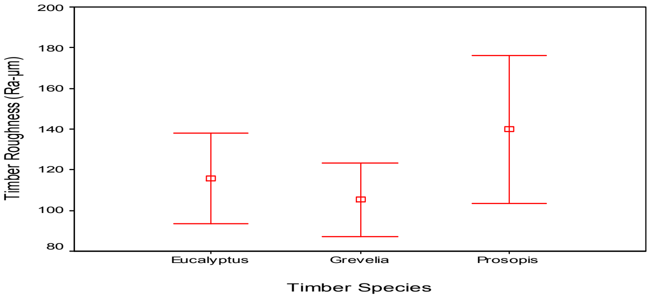

Figure 2. Effect of wood species on sawn timber morphology

Combined Effect of Sawing Systems and Wood Species on Sawn Timber Morphology

The combined effect of sawing systems and wood species on sawn timber surface roughness is shown in Table 3 and Figure 3. The highest mean roughness was recorded in Prosopis timber sawn using Freehand chainsaw system (201.00 ±20.08 µm), which differed significantly from all the other combinations (p = 0.001).

Table 3. Effect of both sawing systems and wood species of timber morphology

Sawing System → Wood Species ↓	FreeHand Chainsaw	Framed Chainsaw	Band saw (control)
Eucalyptus saligna	144.27 ± 35.52	111.70 ± 4.51	91.10 ± 1.37
Grevillea robusta	135.97 ± 6.30	88.87 ±1.12	90.97 ±3.91
Prosopis juliflora	201.00 ±20.08	115.47 ±2.75	103.23 ±2.65

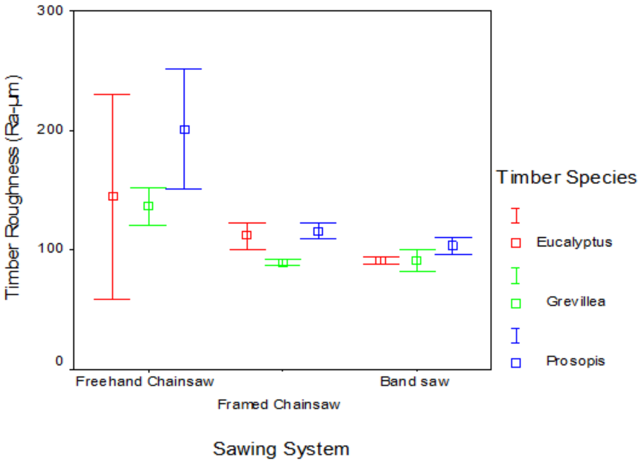

Figure 2. Effect of sawing systems and timber species on sawn timber surface roughness

The rougher surfaces, mainly resulting from the use of freehand chainsaw system were characterized by a much higher variability within the individual timber species as well as among the different species. Grevillea timber sawn using framed chainsaw system had significantly the lowest mean roughness (88.87±1.12 µm) when compared with all the other combinations ($p = 0.000$). This roughness did not however differ from that of same species sawn using band saw system.

DISCUSSIONS

From the results presented, timber size uniformity can be shown to be a factor of both the sawing system design characteristics and wood species properties. Freehand chainsaw produces timber with inconsistent dimensions and high roughness values. This could be attributed to a combination of various factors: During sawing, the operator has to hold the total weight of the machine to keep it in sawing position. This in addition to the back and forth mode of operation of the system and its inherent vibration characteristics could make it difficult for the operator to keep the chain cutting consistently on a straight line. Similarly, the use of only a few cutters (only at the tip of the chain bar) with removed depth gauges increases the cutter aggressiveness and therefore vibration. These characteristics make it more difficult for the operator to control the machine and contribute to both inconsistent timber dimensions and increases surface roughness. In framed chainsaw system, when the frame is attached to the chainsaw, it rests on the log being sawn, taking up the weight of the machine and controlling the chain to cut consistently on the pre-set sawing line. The timber size adjustment bar on the frame is used to set the required timber size, acting in the same way as the machine fence used in the band saw (control). Modification of the felling chain cutters decreases cutter angles as well as controlling the depth gauge clearance instead of removing the depth gauges all together. These two make the cutters less aggressive and therefore stabilize the chain rate of sawing, reducing vibration and hence the variations on the timber size and surface roughness.

There was a clear trend showing that size deviation and surface roughness increased with wood density for all sawing systems. This was pronounced especially for harder species being sawn using freehand chainsaw. This could have been a factor of harder wood resisting the cutters as they bite into the wood, causing saws to vibrate and deviate from the set sawing line (Fehr and Pasiecznik, 2006). Although similar resistance is experienced when framed chain and the band saws are used, the frame is able to hold the chain more firmly on a straight sawing line while the optimized cutters control the vibration of the chain in the wood, thus resulting in smoother timber surface. Similar sawing characteristics are expected for band saws due to the rigidly set and maintained log carriage and the accurately set timber dimensions.

Conclusions

Sawing system have different effects on sawn timber surface morphology due to their differences in design parameters. It has been demonstrated in this study that the design of the cutting tools and timber dimension control mechanisms used on a sawing system has a direct relation with both dimension uniformity and surface roughness of the resultant sawn timber. Freehand chainsaw, commonly used on farms produces sawn timber with rough surfaces and varying dimensions, which is highly associated with the system mode of operation, where no form of dimension control mechanism is used; use of small cutter angles combined with removed depth gauges, making the cutters more aggressive and increasing machine and chain vibration during sawing and the inability of the operator to adequately control the machine during sawing. The framed chainsaw system employs several design parameters: the frame as well as the modified cutter angles and depth gauge clearance. These contribute to improved timber surface quality: the frame controls the chain to consistently saw timber along a straight line, thus contributing to timber size uniformity, while modified angles and depth gauge clearance effectively optimize the sawing speed and reduce the erratic behaviour of the saw, producing sawn timber with smooth surface and uniform dimensions close to timber sawn using a standard machine like the band saws. These parameters make framed chainsaw an eco-efficient small-scale timber sawing system which is reliable in adding value to tree resources while contributing to environmental conservation through increased timber recovery and quality. The system is recommended for timber sawyers operating on the farms, where trees are few, scattered and small in diameter.

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