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Characterization of Sawdust Produced from Circular, Chain and Band Sawing Machines

Bello R. S.

Department of Agriculture & Bio-environmental Engineering Technology, Federal College of Agriculture, Ishiagu, Nigeria

Email address:
segemi2002@gmail.com (Bello R. S.)

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Abstract: Particle size distribution (PSD) of sawdust produced from circular, chain and band sawing machines has been carried out in order to study the influence of different saws on sawdust produced and its characterization. The raw materials were collected from the mill sites and screened, then vibrated on mechanical sieves. Four major fractional classification of particle sizes are identified; oversize particles (OS), coarse particle (CPS), pin particle (PSP) and fine (FSP). The particle size distribution in all the three mills shows a similar pattern of distribution on log sieve graph. The proportion of particle size distribution in FPS produced by all the saw showed slight variations with the least (30.0 ± 1.2%) variation in bandsaw, followed in increasing order by chainsaw and circular saw (37.2 ± 1.3%). Analysis of variance revealed that blade type, particle size, wood density, and particle density are significantly affected by porosity.

Keywords: Sawdust, Sawblade, Chainsaw, Granulometry, Particle Size, Density, Distribution

1. Introduction

Sawdust refers to the tiny-sized and powdery wood waste produced by sawing of wood. research into possible utilization has been conducted in many countries over the years; and received positive attention as partial component for masonry units in building construction [1], fuel resource for its thermal value [2], ethanol production as alternative fuel to petroleum [3], as adsorbent material for the removal of Zn (II) ions from aqueous solutions after treatment with citric acid [4] among several uses. Characterization implies inherent physical, mechanical and combustion characteristics like particle sizes, mass, density, compressive strength, shearing strength, moisture content, total ash content, fixed carbon, volatile matter, gross calorific value that provides its total description and utilization.

Regarding the utilization and quality of sawdust, it is important to pay attention to its physical properties due to the fact that kinds of raw materials, the mill type, and the type of sieve affect these properties [5, 6]. Owing to the availability massive generation of sawdust from sawmills and furniture factories as waste materials, it is largely characterized by irregular shapes and sizes which to a large extent is dependent on the average width of the saw kern, the thickness of the timber sawed and also on the size of the saw teeth [7]. The saw blade factor plays a pivotal role when analyzing the particle size of saw dust and [8], and [9] gave a detailed description of the multiple ways to represent PSD depending on the principles of the measurement and particles' properties.

Result of particle size distribution analysis has been presented in different forms according to particle diameter indicating the nominal mesh sizes, or by particle shapes (fluffy, flaky, cylindrical or spherical), or by particle size distribution, in grams, in percentage by weight of each fraction (differential distribution, as the cumulative percentage of sizes below a given value, or as undersize, cumulative percentage of size above a given value, and as oversize) [10]. Several International Standards which had been severally described in literatures [11, 12] also provide descriptions of some methods/techniques of particle size determination. These methods depend mainly on physical characteristics of analyzed material [13], capital and running costs, varied required specifications and time constraints, which often yielded different results [14, 15].

However, these characteristic methods are not machine specific and are not common for primary log process activities which form the major sources of sawdust production. Since valued products are obtainable from good quality sawdust, this study was undertaken to characterize sawdust produced from three basic sawing machines typically used in primary log processing (chain, band and circular saws) based on particle size distribution, density and porosity parameters.

2. Materials and Method

2.1. Materials

The lignocellulosic feedstock material used in this study is sawdust obtained from assorted wood species produced from three types of primary log conversion machines; chainsaw, circular saw and band saw, a 200 mm diameter column Rupson sieve was used to determine the particle size distribution while an electronic weighing balance was used to determine the material weights.

2.2. Methodology

The methodology employed is presented as follows.

a. Sawdust material preparation

Sawdust samples were collected from three different mill types; power chain saw, circular saw knife with thickness of about 3.0 mm, and band saw with thickness size of 2 mm. the sawdust from each mill were screened for splinters, stones and metals (e.g. nails and iron filings), sun-dried to 8-10% moisture content (mc) dry basis to avoid bio-degradation and was conditioned at atmospheric (at 25°C; 65% RH) for briquetting. The results of granulometric analysis are shown in accordance with ISO 9276-1:1998.

b. Selection of sieves

The selection of the sieves depends on the sample quantity (as mentioned above) and the particle size distribution. The mesh sizes of the sieve stack covered the complete size range of the samples. The distribution function *F* (*d*) (mass fraction) and density function *f* (*d*) (number of particles captured between two screens) of the sample of waste sawdust were obtained from the three different wood cutting devices.

Figure 1. *Fritsch shaker machine with sieve stack mounted and amplitude box.*

c. Determination of particle size and analysis

From each bag, known weighed samples of sawdust particles were separated into different particle sizes using a 200 mm diameter sifting column (Rupson sieve product) placed on a Fritcsh® mechanical vibrating table made in Germany at an amplitude of 150 vibrations/min for 10 min.

For precision in weighing of mass fractions of sawn material, an analytical electronic laboratory weighing balance SF-400 capacity 5000gX1g/177ozX0.1oz, with readability to 0.01 g was used (Figure 2)

Figure 2. *Analytical electronic weighing balance.*

Grain size analysis test and the relative proportions of different grain sizes was carried out using the Fritsch® mechanical sieve shaker.

d. Particle size distribution test

The particle size distribution test follows standard test procedures: From each sample bag, weigh a representative sample (100 g) of dried sawdust was placed on a stack of 5 piece Rupson® standard test sieves arranged from the largest to the smallest opening on the vibrating screen. The setup was vibrated for 10 minutes. The mass retained on each sieve was weighed and the mass of each sieve + retained soil recorded. The procedure was repeat three times for each replicate samples and the percentage of the retained mass on each sieve compared to total mass calculated as the percentage distribution.

The resulting sawdust from each sieve was classified into four fractional sizes: i.e. oversized, coarse, pin and fine. The classification used, was consistent with oversized (OS) for particle size < 24 mesh (>850 µm), coarse particle size (CPS) for particle size 24-60 mesh (500-850 µm), pin particles size (PP) for 60-70 mesh (400-500 µm) and fine particle size (FPS) for 70-80 mesh (177-400 µm).

e. Cumulative percent of material retained

The cumulative percent of material retained in each sieve equals the total amount of material that is retained in each sieve, added up to the amount in the previous sieves. To achieve this, the percentage retained in each sieve is first determined using equation 1 below;

$$\% \, Retained, Rn = \frac{W_S}{W_{Total}} x100\% \quad (1)$$

Where

W_S = the weight of material in the sieve and

W_{Total} = the total weight of the material.

Figure 3. *Sample material retained on each seive.*

Cumulative percent of material retained in the n^{th} sieve

$$\% \, Cum \, retained \; = \sum Rn \qquad (2)$$

The results obtained are tabulated in a table. The values of cumulative percent passing and the sieve sizes are then plotted on a logarithmic graph with cumulative percent passing on the y axis and logarithmic sieve size on the x axis.

f. Geometric mean particle size

Sieve shaker (Fritsch®) was equally used to determine the geometric mean particle sizes. The geometric mean diameter of feedstock was determined using ASAE Standard S319.4 test procedure [16].

Figure 4. *Measure of sample sizes retained on each sieve.*

The geometric mean or equivalent diameter D_{gw}, and geometric standard deviation of the samples in three replicates are calculated using the following equations:

$$D_{gm} = log^{-1}\left[\frac{\sum(m_i log\overline{X_i})}{\sum m_i}\right] \qquad (3)$$

And the standard deviation S_{gm} is given by equation (ANSI/A SAE S424.1 MAR98):

$$S_{gm} = log^{-1}\sqrt{\left[\frac{\sum m_i\left(log\overline{X_i} - logD_{gm}\right)^2}{\sum m_i}\right]} \qquad (4)$$

Where:

m_i *is* the mass of particles on *i*-sieve, (g),

X_i *is* the length of particle on *i*-sieve, (mm) measured with a vernier caliper

$\overline{X_i}$ *is* the mean length (half of sieve diagonal of smallest dimension)of particle on *i*-sieve, (mm).

g. Determination of particle density

The methods employed by [17] was employed in the determination of sawdust particle density following the procedures below.

a. Sawdust was added into a graduated volumetric cylinder to reach the marked 100 cm^3 volume (V_o), and weighed.
b. The weight (g) is determined by subtracting the combined weight of sawdust and volumetric cylinder (W_T) with the weight of empty volumetric cylinder (W_{vs}) alone.
c. Calculate the sawdust - particle density using the formula:

$$Particle \; density \; (gcm^{-3}) = \frac{(W_T - W_{vs})}{V_o} = \frac{W_s}{V_o} \qquad (5)$$

h. Determination of particle porosity

Sawdust porosity is the measure of void volume within sawdust grains, and composed principally of inter-spaces among and intra-spaces within the particles [18, 19], or the percentage of sawdust volume occupied by air and water that filled voids [20]. The method presented by [21] was used to determine the percentage of porosity of sawdust as described below.

a. Sawdust with apparent volume of 100 cm^3 and known weight (Ws in grams) was at first placed in a volumetric cylinder.
b. Tap water was then poured gently into it until the surface of water reached a marked line at the 100 cm^3 level.

Figure 5. *Test samples mixed in glass beakers.*

a. A meshed top stopper was provided at the 100 cm^3 level so that the sawdust, mostly floating on water, would not go beyond its surface.
b. Percentage porosity of sample was expressed as the following formula:

$$Porosity\ (\%) = \left(\frac{V_a}{V_o}\right) \times 100 \quad (6)$$

Where
V_o = The volume of sawdust (100 cm^3).
V_a = The volume of poured water (cm^3) + the sawdust moisture water. The volume of poured water, with the water into the sawdust could be calculated using the formula:

$$Va\ (cm^3) = W_{comb} - W_s - W_{vs} \quad (7)$$

Where
W_{comb} is the combined weight (grams) of volumetric cylinder, sawdust particle, and poured water (gram);
W_s is the weight (gram) of sawdust particles (oven-dry weight equivalent), and
W_{vs} is the weight (grams) of volumetric cylinder. The density of tap water was assumed to be a unity (1 gram cm^{-3}).

3. Results and Discussion

3.1. Results

All test parameters were measured in three replicates and average records for each 100g sample is presented in Tables and charts. The particle size distribution, geometric mean diameter (D_{gw}) and the geometric standard deviation of particle diameter (S_{gw}) were determined using ASAE Standard S319.4 test procedure [16].

Particle size distribution

The proportions of OS, CPS, PP and FPS were determined by weight and the results of average sample particle size distribution is shown in Table 1 below.

Table 1. *Percentage size distribution and sieve analysis of samples.*

1	2	3	4	5	6	7	8	9
Replicate samples	**Sieve Mash #**	**Sieve size (mm)**	**Sieve mass (g)**	**Mass (sieve + retained)** W_{S+SD}	**Retained mass** $W_S(g)$	**% sample retained, Rn**	**Cumm % retained, ΣRn**	**% passing, 100-ΣRn**
Particle distribution from circular sawblade								
	#8	2.36	401.00	406.00	5.00	3.33	3.33	96.67
	#12	1.70	361.00	365.00	4.00	2.67	6.00	94.00
Sample	#20	0.085	349.00	397.00	48.00	32.00	38.00	62.00
average	#35	0.05	370.00	424.00	54.00	36.00	74.00	26.00
	#40	0.04	333.00	372.00	39.00	26.00	100.00	0.00
		Pan	273.00	273.00	0.00	0.00	0.00	0.00
Particle distribution from chainsaw blade								
	#8	2.36	401.00	412.00	11.00	8.00	8.00	92.00
	#12	1.70	361.00	366.00	5.00	3.60	11.60	88.40
Sample	#20	0.085	349.00	391.00	42.00	30.66	42.26	57.74
average	#35	0.05	370.00	398.00	28.00	20.44	62.70	37.30
	#40	0.04	333.00	384.00	51.00	37.23	99.93	0.07
		Pan	273.00	273.00	0.00	0.07	100.00	0.00
Particle distribution from bandsaw blade								
	#8	2.36	401.00	411.00	10.00	6.50	6.50	93.50
	#12	1.70	361.00	362.00	01.00	0.65	7.15	92.85
Sample	#20	0.085	349.00	390.00	41.00	26.80	33.95	66.05
average	#35	0.05	370.00	407.00	37.00	24.20	58.15	41.85
	#40	0.04	333.00	397.00	64.00	41.80	99.95	0.05
		Pan	273.00	273.00	0.00	0.05	100.00	0.00

The particle size distributions of sawdust produced by the three different sawblades generally showed similar proportional distribution trend regardless of other physical variable factors (Figure 6).

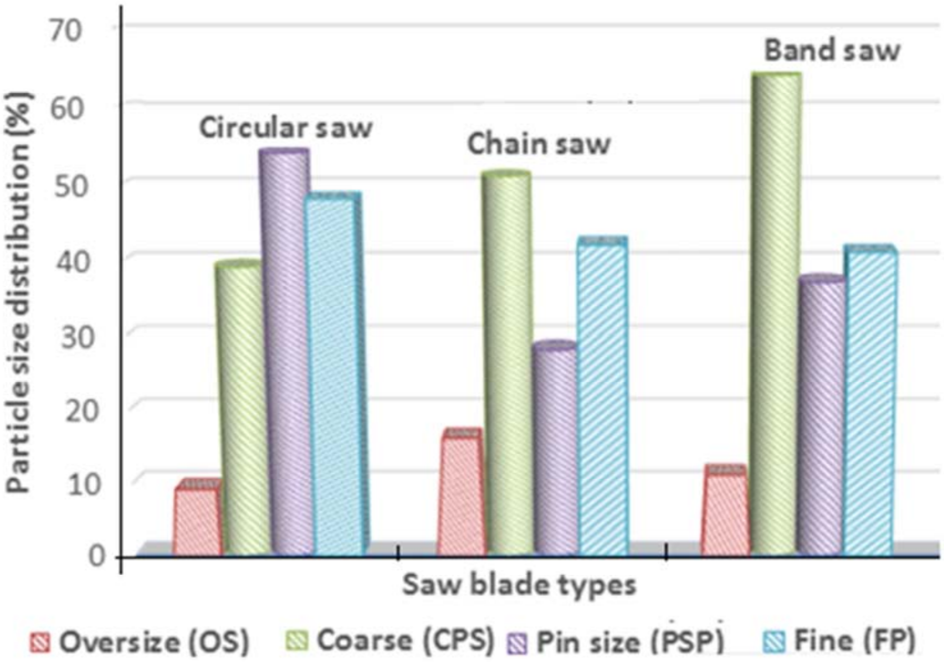

Figure 6. *Particle size distribution of sawdust samples from different mill types.*

Geometric mean particle size, and standard deviation distribution

The results obtained for geometric man particle size and standard deviation are shown in Table 2. Length of particles on the first sieve (X_1) measured with a vernier caliper averaged to 48 mm for all samples. The mean length of particle on the bottom (X_6) equal 0.82 mm (half of sieve diagonal of smallest dimension). Results showed that the materials has an average of 6-8 mm size distribution with 10-20% powdery component (< 4 mesh); this result is known to give better products and as such requires no further grinding.

Table 2. *Geometric mean particle size distribution of samples from different blades.*

ASTM Mesh #	Sieve size (mm)	Mass retained, W_S(g)	Particle length on i-sieve X_i			Mean length, $\bar{X}_i$	Geometric mean diameter D_{gw}
			X_1	X_2	X_3		
Particle distribution from circular saw materials							
#8	2.36	5.00	11.00	8.00	6.00	8.33	
#12	1.70	4.00	7.00	4.00	6.00	5.67	
#20	0.085	48.00	4.00	3.00	4.00	3.67	0.65
#35	0.05	54.00	3.00	4.00	3.00	3.33	
#40	0.04	39.00	2.00	3.00	2.50	2.50	
	$\sum W_S$=150						
Particle distribution from chainsaw materials							
#8	2.36	11.00	7.00	8.00	8.50	7.83	
#12	1.70	5.00	5.00	7.00	5.50	5.84	
#20	0.085	42.00	6.00	4.50	5.00	5.17	0.47
#35	0.05	28.00	4.00	3.50	5.00	4.17	
#40	0.04	51.00	3.00	2.50	3.50	3.00	
	$\sum W_S = 137$						
Particle distribution from bandsaw materials							
#8	2.36	10.00	15.00	14.00	13.00	14.00	
#12	1.70	1.00	10.00	9.00	8.5.00	9.17	
#20	0.085	41.00	4.00	5.00	6.00	5.00	0.86
#35	0.05	37.00	2.00	2.50	2.00	2.17	
#40	0.04	64.00	1.00	2.00	1.50	1.50	
	$\sum W_S$=153.00						

Length of particles on the first sieve (X_1) measured with a vernier caliper averaged to 14 mm for bandsaw samples. The mean length of particle on the bottom (X_6) equal 1.5 mm (half of sieve diagonal of smallest dimension). Results showed that the materials has an average of 6-8 mm size distribution with 10-20% powdery component (< 4 mesh); this result is known to give better products and as such requires no further grinding [22].

Particle density distribution

The experimental results obtained during the determination of particle density in each of the sample materials from different mills are shown in Table 3.

Table 3. *Density distribution of samples.*

Replicate samples	Beaker mass W_{vs}(g)	Mass (beaker + sample) W_T	Sample mass $W_S(g)$	Volume of sawdust, V_o	Density (g/cm^3)
Density distribution of circular samples					
1	250.00	430.00	180.00	900.00	0.20
2	250.00	400.00	150.00	750.00	0.20
3	250.00	415.00	165.00	800.00	0.21
Mean	250.00	415.00	165.00	816.67	0.20
Density distribution of chainsaw samples					
1	250.00	428.00	180.00	610.00	0.30
2	250.00	400.00	150.00	580.00	0.26
3	250.00	415.00	165.00	600.00	0.28
Mean	250.00	414.33	165.00	596.67	0.28
Density distribution of bandsaw samples					
1	250.00	330.00	80.00	600	0.13
2	250.00	340.00	90.00	625	0.14
3	250.00	320.00	70.00	500	0.14
Mean	259.00	330,00	80.00	575	0.14

A comparison result of particle density among different mills showed a similar pattern for each wood species with the particle density produced by bandsaw was the smallest both in CPS and in FPS, followed in an increasing order by chainsaw and by circular.

Combining the value of particle density for all sawdust from each different mill indicated that the average density ± SD of the particle density produced by bandsaw (0.14 ± 0.50 g cm^{-3}) was smaller than that by circular saw (0.20 ± 0.89 g cm^{-3}) and by chainsaw milling (0.28 ± 16 g cm^{-3}) (Table 4). This pattern is probably due to variations in blade size on each mill.

Table 4. *Standard deviation of samples.*

Sieve size (μm)	Mass retained, $W_S(g)$	Mean length, $\overline{X_\iota}$	$Log\overline{X_\iota}$	Log, D_{gm}	$(log\overline{X_\iota} - logD_{gm})^2$	$\sum m_i(log\overline{X_\iota} - logD_{gm})^2$	$\frac{\sum m_i(log\overline{X_\iota} - logD_{gm})^2}{\sum m_i}$	S_{gm}
Particle distribution from circular saw materials $\sum W_S = 150$								
2.36	5.00	8.33	0.92		0.53	2.65		
1.70	4.00	5.67	0.75		0.31	1.24		
0.085	48.00	3.67	0.57	0.19	0.15	7.20	0.168	0.89
0.05	54.00	3.33	0.52		0.11	5.94		
0.04	39.00	2.50	0.40		0.21	8.19		
Particle distribution from chain saw materials $\sum W_S = 137.00$								
2.36	11.00	7.83	0.89		0.31	3.41		
1.70	5.00	5.84	0.77		0.19	0.95		
0.085	42.00	5.17	0.71	0.33	0.14	5.88	0.099	1.16
0.05	28.00	4.17	0.62		0.08	2.24		
0.04	51.00	3.00	0.48		0.02	1.02		
Particle distribution from band saw materials $\sum W_S = 153$								
2.36	10.00	14.00	1.15		1.17	11.70		
1.70	1.00	9.17	0.96		0.79	0.79		
0.085	41.00	5.00	0.70	0.07	0.40	16.4	0.37	0.50
0.05	37.00	2.17	0.34		0.73	27.01		
0.04	64.00	1.50	0.18		0.01	0.64		

This study also demonstrated the strong effect of wood density and particle size classes on particle density of sawdust. Although it has been generally accepted that wood density influences particle density, this study shows that different mill and particle size classes also influence particle density for each sample.

The results of particle porosity obtained are shown in Table 5.

Table 5. *Porosity distribution of samples.*

Replicate samples	**Beaker mass** $W_{vs}(\mathbf{g})$	**Mass (beaker + sample)** W_T	**Sample mass** $W_S(g)$	**Combined mass** $W_{comb}(\mathbf{g})$	**volume of sawdust,** V_o	**Poured volume** V_a (cm^3)	**Porosity** (cm^3)
Circular samples porosity							
1	250.00	430.00	180.00	1253.00	900.00	643.00	1.40
2	250.00	400.00	150.00	1254.00	750.00	704.00	1.07
3	250.00	415.00	165.00	1227.00	800.00	647.00	1.24
	250.00	415.00	165.00	1244.67	816.67	664.67	1.24
Chainsaw samples porosity							
1	250.00	330.00	80.00	1233.00	600.00	823.00	0.73
2	250.00	340.00	90.00	1234.00	625.00	804.00	0.78
3	250.00	320.00	70.00	1225.00	500.00	835.00	0.60
	250.00	330.00	80.00	1244.00	575.00	820.67	0.70
Bandsaw samples porosity							
1	250.00	428.00	180.00	1273.00	610.00	843.00	0.72
2	250.00	400.00	150.00	1285.00	580.00	885.00	0.66
3	250.00	415.00	165.00	1257.00	600.00	842.00	0.71
Total	250.00	212.33	165.00	1271.67	596.67	856.67.00	0.70

3.2. Discussions

Due to the heterogeneous and fluffy nature of the particle sizes of the collected sawdust samples, the sawdust was classified into four fractional sizes: i.e. oversized, coarse, pin and fine. A grading curve of log sieve size vs % passing plotted in Figure 7 shows similar particle distribution pattern.

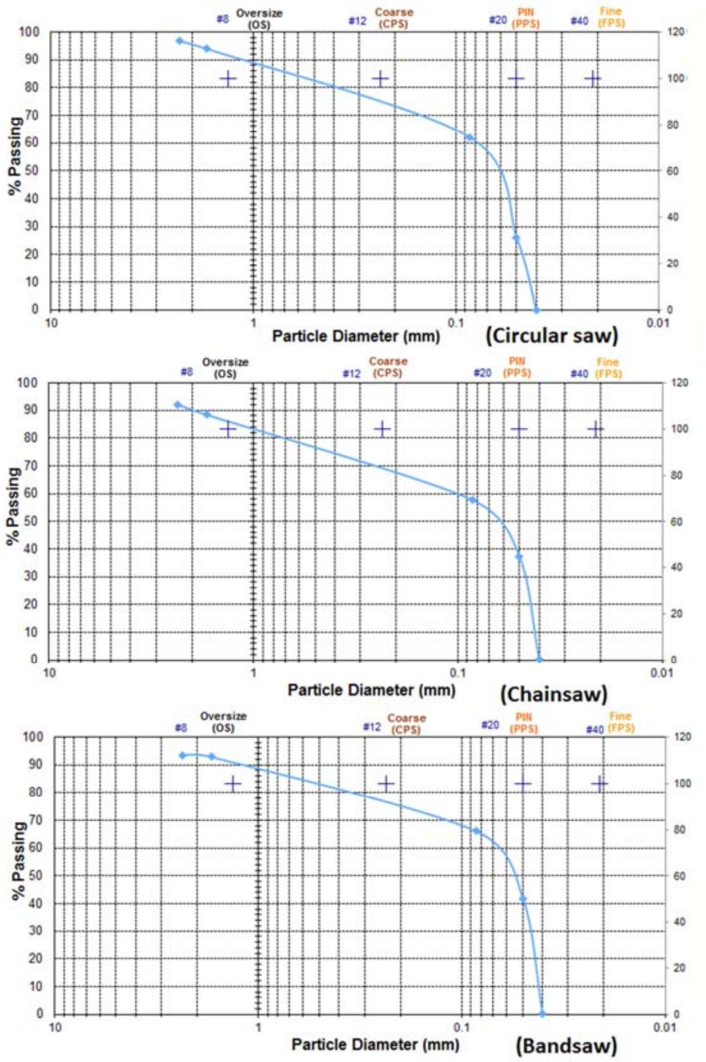

Figure 7. *Graph of log sieve size vs % particle passing.*

The classification shows consistency with oversized (OS) used for particle size < 24 mesh (>850 µm), coarse particle size (CPS) for particle size 24-60 mesh (500-850 µm), pin particles size (PP) for 60-70 mesh (400-500 µm) and fine particle size (FPS) for 70-80 mesh (177-400 µm). The proportion of oversized particles (OS) was generally lower than that of coarser particle size (CPS) and fine particle size (FPS) regardless of sawblade type. However, comparing the proportions of particle size distribution for each mill revealed a different size distribution. Consequently, this pattern affects the proportion of particle size in other classes, e.g. the proportion of particle size distribution in FPS produced by all the saw showed slight variations but was the smallest (30.0 ± 1.2%) in bandsaw, followed in an increasing order by chain saw and circular saw (37.2 ± 1.3%). It can be concluded that the mill types influenced particle size distribution (OS, CPS, and FPS).

A similar pattern was reported by [23] and [24] Analysis of variance (GLM) revealed that all the variables tested, i.e. mill types, particle size, wood density, and sawdust's particle density significantly affected the porosity (Table 4). Further, a comparison of porosity patterns between different mills for each tree species showed slight differences in CPS as well as in FPS. Related with such combining the value of porosity for all tree species showed that the average porosity of sawdust particle (CPS and FPS) produced by handsaw (CPS = 77.4 ± 7.5%; FPS = 74.7 ± 7.4%) was higher than that by sawmill (CPS = 76.2 ± 6.6%; FPS = 73.1± 6.5%) and by milling (CPS = 73.9 ± 4.2%; FPS = 71.0 ± 4.1%).

4. Conclusions

The particle size distribution of sawdust collected from three different mills; circular, chain and band saws has been carried out. By the described method the dimensional characteristics of sawdust, and other fractal particles can be measured. The particle size distributions produced are of slightly of different shapes due to differences in teeth geometries. Four major fractional particle classifications are identified; oversize particles (OS), coarse particle (CPS), pin particle (PSP) and fine (FSP). The proportion of oversized particles (OS) was generally lower than that of coarser particle size (CPS) and fine particle size (FPS) regardless of sawblade type. However, comparing the proportions of particle size distribution for each mill that the proportion of particle size distribution in FPS produced by each saw showed slight variations; smallest in bandsaw (30.0 ± 1.2%), followed in an increasing order by chain saw and circular saw (37.2 ± 0.3%). One other significant aspect of this outcome in woodcutting is the possibility of determining wood effect on tool wear thereby restructuring machining economy [25].

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