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DETERMINATION OF ATTRITION RATE OF LOCALLY MANUFACTURED PLATES FOR CORN MILLING

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ABSTRACT

Corn milling is a method of processing corn by crushing it between two contacting circular metallic plates. During instances where the blades had worn out, greater energy is required, hence the need to determine the wear rate of the corn mill blades. By knowing the wear rate of the corn mill blades, millers will have the exact knowledge of the quantity of products that can be milled to avoid usage of worn out blades. In this research 4 pairs of blades were used at separate times to determine their attrition rate. On each pair of the blades, twelve different evenly separated ridges were marked and their average height is taken before and after use to find the changes in height they undergo whenever they are used. Likewise, the mass to estimate the change in mass. The pairs of blades were re-horned (re-sharpened) for the next usage. This experiment is repeated three times for each pair of blades. At the end of the experiment, a range of 0.01 to 0.05mm/bag attrition rate for changes in ridges height was observed for quantities of maize ranging from 9.5 bags to 21.5 bags. It was observed that the slender the ridge the higher the specific attrition (mm/bag). It can be concluded that the amount of material (particles) lost from the plates through attrition is between 0.02 to 0.05 kg of metal for 9.5 bags to 21.5 bags of corn. This variation is dependent on the nature of the ridges on the plates. An average of 37.97 MJ of energy was generated as heat energy which is deposited into the milled product. In this way, the by-product acts as a coolant and had an average rise in temperature of 19.13 to 21.68 ^{o}C. Finally, to ensure efficient use of the plates and food safety, a pair of locally manufactured plates should be changed after milling about 14 bags of wet corn for an attrition rate of about 0.028 mm/bag.

Keywords: *Attrition rate; re-hone; pair of plates, bags of corn; slender*

1.0 INTRODUCTION

Corn (popularly known as maize) is the seed of a grass species botanically called Zea Mays L (Kpodo, Thrane, & Hald, 2000; Johnson & Halm, 1998). It is a monocot crop which is usually planted and harvested twice and once in a year in the Southern and Northern parts of Ghana, respectively, (Awunyo-Vitor, Wongnaa, & Aidoo, 2016). Corn is the largest produced cereal (ISSER, 2013) and the most widely consumed staple food in Ghana with increasing production since 1965 (Nago, Hounhouigan, Akissoe, Zanou, & Mestres, 1998; SARI, 1996). The production rate reported for 2007 and 2010 was 1.5 million MT with a 1.7 t/ha yield (SRID-MoFA, 2011; Rondon and Ashitey, 2011).

Maize is also the largest staple crop in Ghana and contributes significantly to consumer diets (Awunyo-Vitor, Wongnaa, & Aidoo, 2016). It is the number one crop in terms of area planted

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(about 1,000,000 hectares) and accounts for 50-60% of total cereal production in Ghana, (Addai & Owusu, 2014). Additionally, maize is the second largest commodity crop in the country after cocoa, (Rondon and Ashitey, 2011; SARI, 1996; ISSER, 2013). Maize is one of the most important crops produced in Ghana's agricultural sector to enhance food security (Johnson & Halm, 1998; ISSER, 2013; Nago, et al., 1998). In Ghana, it is grown in the forest, transition, southern regions, upper west, upper east and northern regions of Ghana and this is an indication of how widely the crop is grown in the country, (Amanor-Boadu, 2012). As a result, almost all the estimated 92 ethnic groups in the country consume a considerable amount of maize, (Adjei-Nsiah, Kuyiper, Leeuwis, Abekoe, & Giller, 2007; Bempomaa & Acquah, 2014). Approximately 80% of the locally produced maize or corn is used by food vendors and consumed directly by households while 15% is used to produce animal feeds (poultry and livestock) and about 5% used by industries (breweries, confectioners and poultry) to produce a variety of products such as sweeteners, starches, oils, ethanol, (Johnson & Halm, 1998; Nago, et al., 1998; Bempomaa & Acquah, 2014).

As already stated, maize is a staple food in Ghana so it is not a wonder that almost all the ethnic groups in the country consume considerable amounts of maize (Acquah & Kyei, 2012; Johnson & Halm, 1998). Maize is also an important component of poultry and livestock feeds as well as a substitute for the brewing industry. In the light of the above, a good number of corn mills have been installed across the country for maize processing, (Ampadu-Mintah, 2008; Andrews & Kwofie, 2010; Kwofie & Chandler, 2006).

Wet and dry milling are the two predominantly methods used for processing maize for food preparation in homes, schools, hospitals, restaurants and hotels as well as animal feed (Johnson & Halm, 1998; Owolabi, Omidiji, & Olugbade, 2014; Andrews & Kwofie, 2010; Ampadu-Mintah, 2008). Each of these two methods produces a product that defers from the other in terms of moisture content. The wet milling produces relatively wet product compared to that of the dry milling.

A mill is a device that breaks solid materials into smaller pieces by grinding, crushing, cutting or shearing, (Andrews & Kwofie, 2010; Ampadu-Mintah, 2008; Bothwell, Seftel, Jacobs, Torrance, & Baumslag, 1964; Deugnier, et al., 1992). Maize milling is a method of processing maize for safe consumption. The process of wet milling begins with cleaning the grain followed by the conditioning (dampening) of the maize with water for some time. Usually, the degree of quality of the cornflour produced depends on the health of the machine and how the operator manipulates it.

As more grains of corn are ground, the circular discs (plates) of the corn mill experience relative motion leading to wearing of the discs with time, (Bothwell, et al., 1964; Deugnier, et al., 1992; Ampadu-Mintah, 2008; Andrews & Kwofie, 2010). The wearing of these plates in service causes metal (iron) debris to mix with the milled corn and this could pose health hazards to consumers. During instances where the plates get worn out, greater energy is required to mill any amount of grain, (Schorno, 2006; Dijkink & Langelaan, 2002; Carter, 2006). When the depth of the ridges reduces, greater energy is required when a large amount of corn is feed into the hopper at a particular time for milling, hence the need to determine the wear or attrition rate of the corn mill plates. By knowing the wear rate of corn mill plates, millers will have good

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knowledge about the right quantity of products that can be milled to avoid usage of worn out plates.

To avoid the situation of using worn out plate, corn mill operators usually disassemble the plate now and then to check the state of the plate, which consequently affect working hours. There is also the need to determine the wear rate of corn mill plates to reduce downtimes, arrange for a replacement, minimize the tendency of contaminating the milled product and to provide corn millers in Ghana with a fair idea about the right time to change worn out plates before they expose the lives of milled maize consumers to health risk without carrying out any complex laboratory test or operation, (Andrews & Kwofie, 2010; Deugnier, et al., 1992; Owolabi, et al., 2014).

The purpose of this paper is to provide corn mill operators with a basic technique for examining plates of corn milling machines especially locally manufactured ones for them to easily identify and timely change plates that are wearing out at unacceptable rates. Such plates if not changed at the appropriate time become life-threatening since the worn-out particles mix smoothly with the milled corn and if consumed in greater proportions may affect the health of consumers, (Kwofie & Chandler, 2006).

Interviews done by this paper revealed that the operators of corn mills in Ghana are not regulated by any law and no regular checks are made by any regulatory body to ensure that their operations are not detrimental to the lives of consumers. It is very interesting to note that, most of the corn milling plates used in corn milling machines installed over the years or used in the country are locally made, (Kwofie & Chandler, 2006). These plates are not made to any specifically approved standard and are not being certified as expected by any mandatory body in Ghana before they are marketed, (Kwofie & Chandler, 2006). It is against this backdrop that this paper presents a very simple but effective method of ensuring that locally manufactured corn mill plates are used appropriately. The time it takes for the blades to wear out was not measured in this experiment, rather the number of bags of corn milled because the blades were not used continuously until it is worn out.

This paper finds the method is adopted to determine the attrition rate of corn mill plates as very effective and appropriate since corn mill operators would find it very cumbersome to undertake complex laboratory tests to determine the amounts of constituents of maize before and after milling to establish whether there had been increased or decrease in the various constituents to ascertain whether or not the processed maize is unreasonably contaminated.

2.0 MATERIALS AND METHOD

The attrition rates of locally manufactured plates were determined since most of the corn mill centres in Ghana largely use locally manufactured corn mills and for that matter, locally manufactured plates, (Kwofie & Chandler, 2006). Even the few corn mill centres installed with imported corn mills rely on locally manufactured plates when their plates are destroyed. This is primarily due to unavailability and the relatively high cost of imported corn mill plates.

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Locally manufactured corn mill plates are produced from scrap metals and are most often fabricated by artisans having little or no knowledge about solid mechanics or strength of materials as an area of speciality in Mechanical Engineering, (Kwofie & Chandler, 2006). The constituents of these locally manufactured plates are Iron, Carbon, Magnesium, Phosphorus, Silicon, Nickel, Aluminium, Boron, Copper, Sulphur, Tin, Vanadium and Chromium, (Kwofie & Chandler, 2006).

These plates are not made to any approved standard by the local artisans and for this reason, such a study must be carried out to ensure that maize ground by the plates under review do not cause any health problems as a result of the mixing of the worn-out particles of the plate with the processed maize, (Ampadu-Mintah, 2008; Andrews & Kwofie, 2010; Kwofie & Chandler, 2006). The main responsibility of the artisans as far as the production of the plates is concerned is to make sure that the plates are thick and strong enough to crush the maize smoothly to a texture which is acceptable and satisfactory to clients and that the processed product will be safe for consumption. Slender plates wear at a faster rate than thicker plates.

The following list is the materials, tools and equipment used to carry out the project; Four pairs of locally manufactured corn mill plates, digital Vernier calliper, Laser thermometer, Electronic balance, Metal grinding machine and Milling machine. Four pairs of blades were seen to be appropriate as averagely a corn mill operators make use of two pairs of the blade in a month during their busiest times. This number will also make it possible to capture the possibility of having different blades in the market.

The digital Vernier calliper was used to take the height of the ridges on the plates before and after being used for grinding a given quantity of maize while the laser thermometer was used to determine the temperature of the unprocessed and processed maize. The Electronic balance was used to measure accurately the mass of maize before processing as well as the mass of the plates before and after use during the series of stages (first, second and third usage) in which the plates were used for the experiment. The Metal grinding machine was used to remove tiny burrs on the new plates before they were used for the test while the Corn milling machine was the machine used for the processing of the maize. In this research, the time it takes for the blade to wear out completely was not measured and this became necessary because the blades were not used continuously until they are worn out.

This research began with the selection of corn mill plates with the help of corn millers or corn mill machine operators. The blades used are the locally manufactured type which is commonly used by almost all the operators in the country. This type happens to be the most used blade as the production of blades is yet to be standardised despite its effectiveness during usage. In all, 4 pairs of plates were procured that best suits the milling task (they were labelled O_1O_2, X_1X_2, I_1I_2, and N_1N_2, where subscript 1 is the free plate whiles subscript 2 is the fixed plate). Figure 1 shows a typical corn milling machine plate with series of ridges (that appear individually like involute and collectively a given number of them appear to form a frustum as depicted by the plate shown in Figure 1) produced on the face of a disc.

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Figure 1: A typical Plate with ridges

On each pair of plates, twelve different evenly separated ridges were marked for identification and use in experiments. The ridges of the plates did not have uniform height on the faces of the honed or sharpened plates so the heights of the higher and lower points of the twelve marked ridges were measured and used as the reference heights (i.e. average height). These reference heights were taken before and after the pair of plates were used. This was done to find the change in height of the ridges. Likewise, the mass of the plates before and after use were also measured and recorded to estimate the change in mass after every use of the plates for the milling of the maize.

The corn product (i.e. milled corn) at the end was found to be warmer than its initial temperature due to the effect of thermal energy generated by the rubbing surfaces between the pair of plates. To estimate the rise in temperature, the temperature of the raw corn and the milled corn were taken at an interval of 20 minutes with a stopwatch. The pairs of plates were used thrice for grinding three different masses of maize in one set of experiment. The reduction in height of the marked ridges of the plates was observed and recorded after milling given quantities of maize.

The process was repeated the same number of times (3 times) for all the other selected pairs of plates. The specific wear i.e. the wear of plate per mass of maize ground of the selected pairs of plates were measured and recorded at various stages of the experiment

3.0 RESULTS AND DISCUSSION

The Tables (i.e. Table 2-5) and Figures in this part of the paper give a far-reaching illustration and examination of the wear which occurred on the marked ridges. Likewise, the temperature (heat energy caused by friction generated from the rubbing surfaces) generated in the course of milling which also contributed to the wearing of the plates was also measured. The first set of plates labelled O_1O_2 were used three times in this order of bags of corn; 9.5 (950 kg), 17.5 (1750 kg) and 22 (2200 kg). One bag is believed to be 100 kg.

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Table 1 shows typical results obtained from the research. It shows the changes in temperature and mass at each run of usage. The logger registered an average temperature of 19.13 ^oC, 20.09 ^oC and 21.68 ^oC and a reduction in mass of 0.02 kg of metal, 0.3 kg of metal and 0.03 kg of metal, respectively for the various usage of the plate pair O_1O_2. Plate pair N_1N_2 recorded 20.06 ^oC, 20.34 ^oC and 20.34 ^oC for the increase in temperature and a reduction in mass of 0.03 kg of metal, 0.02 kg of metal and 0.02 kg of metal, respectively, for the following 500 kg, 1200 kg and 2000 kg of corn. When 2200 kg, 2150 kg and 950 kg of maize were ground, the increment in temperature and reduction in mass for the plate pair X_1X_2 was 19.45 ^oC, 18.50 ^oC and 23.83 ^oC; and 0.28 kg of metal, 0.03 kg of metal and 0.04 kg of metal, respectively. The use of plate pair I_1I_2 also recorded changes in both temperature and mass of the plate for the following masses of corn 1000 kg, 1500 kg and 1550 kg. The temperatures are 16.06 ^oC, 18.63 ℃ and 20.13 ^oC whiles the masses were 0.03 kg of metal, 0.34 kg of metal and 0.04 kg of metal respectively.

The rubbing forces between each pair of plates cause the ridges to wear out. Table 2 and Figures 2 and 2 show the wearing dynamics of corn mill plate for given quantities of corn.

Table 1: Changes in temperature and mass of corn and Plate pair O_1O_2

1st use Plate	Before Milling Mass/kg	After Milling Mass/kg	Change in Mass after 9.5 bags
O1	4.82	4.80	0.02
O2	4.77	4.75	0.02
Average	**4.80**	**4.78**	**0.02**

Time /min	T(in)	T(out)	ΔT
0	28.90	48.20	19.30
20	29.80	44.60	14.80
40	29.40	47.90	18.50
60	28.70	50.20	21.50
80	29.00	51.50	22.50
100	30.80	48.70	17.90
120	31.70	49.60	17.90
140	29.78	50.40	20.62
Average	**29.76**	**48.89**	**19.13**

2nd use Plate	Before Milling Mass/kg	After Milling Mass/kg	Change in Mass after 17.5 bags
O1	4.63	4.32	0.31
O2	4.59	4.30	0.29
Average	**4.61**	**4.31**	**0.30**

Time /min	T(in)	T(out)	ΔT
0	29.50	48.70	19.20
20	29.70	48.50	18.80
40	30.30	50.10	19.80
60	29.30	50.30	21.00
80	28.90	51.20	22.30
100	29.80	49.50	19.70
120	30.20	49.30	19.10

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140	29.70	50.50	20.80
Average	**29.68**	**49.76**	**20.09**

3rd use Plate	Before Milling Mass/kg	After Milling Mass/kg	Change in Mass after 22 bags
O1	4.17	4.15	0.02
O2	4.17	4.12	0.05
Average	**4.17**	**4.14**	**0.03**

Time /min	T(in)	T(out)	ΔT
0	28.40	49.60	21.20
20	29.30	49.70	20.40
40	29.80	49.40	19.60
60	30.10	50.30	20.20
80	30.40	51.40	21.00
100	20.30	50.60	30.30
120	31.20	52.10	20.90
140	31.00	50.80	19.80
Average	**28.81**	**50.49**	**21.68**

Table 2: Parameters of Plate before and after use for Plate pair O_1O_2

(a) Plate O_1, before 1st use							
Mark	EXTERNAL		INTERNAL		HEIGHT OF RIDGE		
	RIDGE	GROOVE	RIDGE	GROOVE	EXTERNAL	INTERNAL	AVERAGE
	a_e	b_e	a_i	b_i	$a_e - b_e = h_{e1}$	$a_i - b_i = h_{i1}$	$(h_{e1} + h_{i1})/2 = h_1$
1.00	14.29	13.68	11.41	9.60	0.61	1.81	1.21
2.00	13.59	12.83	11.35	8.86	0.76	2.49	1.63
3.00	13.21	12.51	11.47	10.50	0.70	0.97	0.84
4.00	13.34	12.75	11.74	10.23	0.59	1.51	1.05
5.00	13.16	12.72	10.92	10.68	0.44	0.24	0.34
6.00	13.10	12.21	9.98	9.28	0.89	0.70	0.80
7.00	13.14	12.40	11.70	8.81	0.74	2.89	1.82
8.00	13.19	12.60	9.06	8.95	0.59	0.11	0.35
9.00	13.83	12.93	10.94	8.59	0.90	2.35	1.63
10.00	13.84	13.47	11.02	9.17	0.37	1.85	1.11
11.00	14.40	13.58	11.92	8.85	0.82	3.07	1.95
12.00	14.31	13.32	11.33	8.58	0.99	2.75	1.87
Average	**13.62**	**12.92**	**11.07**	**9.34**	**0.70**	**1.73**	**1.21**

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(b) Plate O_2, after 1st use (9.5 Bags)

Mark	EXTERNAL		INTERNAL		HEIGHT OF RIDGE			CHANGE IN HEIGHT AFTER USE	WEAR FACTOR L/bags
	RIDGE	GROOVE	RIDGE	GROOVE	EXTERNAL	INTERNAL	AVERAGE		
	a_e	b_e	a_i	b_i	$a_e - b_e = h_{e2}$	$a_i - b_i = h_{i2}$	$(h_{e2} + h_{i2})/2 = h_2$	$b = abs(h_{i2}-h_{i1})$	$W_a=b/9.5$
1	12.60	12.47	10.55	9.02	0.13	1.53	0.83	0.43	0.05
2	12.90	12.31	10.31	9.67	0.59	0.64	0.62	0.62	0.07
3	12.81	11.59	10.41	8.37	1.22	2.04	1.63	0.26	0.03
4	12.63	12.12	10.62	10.06	0.51	0.56	0.54	0.46	0.05
5	13.21	13.05	10.72	8.38	0.16	2.34	1.25	1.65	0.17
6	13.42	12.58	10.43	9.01	0.84	1.42	1.13	0.44	0.05
7	13.21	12.50	10.48	9.05	0.71	1.43	1.07	0.27	0.03
8	12.42	12.09	10.16	8.33	0.33	1.83	1.08	0.01	0.00
9	12.04	11.54	10.58	8.24	0.50	2.34	1.42	1.08	0.11
10	12.40	11.52	11.13	8.83	0.88	2.30	1.59	0.54	0.06
11	12.62	12.20	10.88	9.33	0.42	1.55	0.99	0.02	0.00
12	12.34	11.84	10.75	8.06	0.50	2.69	1.60	0.10	0.01
Average	**12.72**	**12.15**	**10.59**	**8.86**	**0.57**	**1.72**	**1.14**	**0.49**	**0.05**

Table 3: Parameters of Plate before and after use for Plate pair I_1I_2

(a) BLADE I_1, BEFORE 1ST USE

Mark	EXTERNAL		INTERNAL		HEIGHT OF RIDGE		
	RIDGE	GROOVE	RIDGE	GROOVE	EXTERNAL	INTERNAL	AVERAGE
	a_e	b_e	a_i	b_i	$a_e - b_e = h_{e1}$	$a_i - b_i = h_{i1}$	$(h_{e1} + h_{i1})/2 = h_1$
1	14.27	12.63	12.89	10.31	1.64	2.58	2.11
2	13.86	13.08	11.72	8.85	0.78	2.87	1.83
3	13.70	13.02	11.70	11.37	0.68	0.33	0.51
4	14.95	13.61	10.87	8.95	1.34	1.92	1.63
5	14.69	14.14	11.81	10.99	0.55	0.82	0.69
6	14.31	13.75	12.12	10.14	0.56	1.98	1.27
7	13.92	13.50	12.09	9.41	0.42	2.68	1.55
8	13.69	13.26	11.72	10.10	0.43	1.62	1.03
9	13.35	13.15	11.59	9.71	0.20	1.88	1.04
10	13.39	12.50	12.17	9.48	0.89	2.69	1.79
11	13.75	13.09	13.13	11.01	0.66	2.12	1.39
12	13.53	12.59	12.06	10.81	0.94	1.25	1.10
Average	**13.95**	**13.19**	**11.99**	**10.09**	**0.76**	**1.90**	**1.33**

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(b) BLADE I_2, AFTER 1ST USE (10 Bags)									
Mark	EXTERNAL		INTERNAL		HEIGHT OF RIDGE			CHANGE IN HEIGHT AFTER USE	WEAR FACTOR L/bags
	RIDGE	GROOVE	RIDGE	GROOVE	EXTERNAL	INTERNAL	AVERAGE		
	a_e	b_e	a_i	b_i	$a_e - b_e = h_{e2}$	$a_i - b_i = h_{i2}$	$(h_{e2} + h_{i2})/2 = h_2$	$b = abs(h_{i2}-h_{i1})$	$W_a=b/10$
1	13.03	12.26	9.35	9.12	0.77	0.23	0.50	1.11	0.11
2	12.27	12.08	10.23	7.45	0.19	2.78	1.49	0.74	0.07
3	12.61	12.17	10.11	7.89	0.44	2.22	1.33	0.26	0.03
4	12.74	12.13	11.15	7.34	0.61	3.81	2.21	0.03	0.00
5	12.98	12.28	9.55	8.00	0.70	1.55	1.13	0.13	0.01
6	13.22	12.71	9.80	9.36	0.51	0.44	0.48	0.10	0.01
7	13.25	12.74	10.29	8.68	0.51	1.61	1.06	0.21	0.02
8	12.54	11.90	10.37	9.24	0.64	1.13	0.88	0.41	0.04
9	12.42	12.31	9.00	8.49	0.11	0.51	0.31	0.71	0.07
10	12.13	11.92	10.32	7.51	0.21	2.81	1.51	0.09	0.01
11	11.60	11.32	9.54	9.13	0.28	0.41	0.34	0.49	0.05
12	11.70	11.98	10.37	8.74	-0.28	1.63	0.67	0.64	0.06
Average	**12.54**	**12.15**	**10.01**	**8.41**	**0.39**	**1.59**	**0.99**	**0.41**	**0.04**

Table 4: Parameters of Plate before and after use for Plate pair N_1N_2

(a) BLADE N_1, BEFORE 1ST USE							
Mark	EXTERNAL		INTERNAL		HEIGHT OF RIDGE		
	RIDGE	GROOVE	RIDGE	GROOVE	EXTERNAL	INTERNAL	AVERAGE
	a_e	b_e	a_i	b_i	$a_e - b_e = h_{e1}$	$a_i - b_i = h_{i1}$	$(h_{e1} + h_{i1})/2 = h_1$
1	14.96	14.72	13.96	8.96	0.24	5.00	2.62
2	14.01	13.29	12.03	8.12	0.72	3.91	2.32
3	13.29	13.01	12.44	7.86	0.28	4.58	2.43
4	13.31	12.00	13.26	8.75	1.31	4.51	2.91
5	13.04	11.74	12.59	11.32	1.30	1.27	1.29
6	12.63	11.82	12.10	9.53	0.81	2.57	1.69
7	13.88	12.03	13.72	10.21	1.85	3.51	2.68
8	14.30	13.38	14.11	9.61	0.92	4.50	2.71
9	14.39	13.55	13.53	8.76	0.84	4.77	2.81
10	13.96	12.86	12.31	9.03	1.10	3.28	2.19
11	13.69	13.22	13.01	10.02	0.47	2.99	1.73
12	13.85	13.63	13.56	9.89	0.22	3.67	1.95
Average	**13.78**	**12.94**	**13.05**	**9.34**	**0.84**	**3.71**	**2.28**

(b) BLADE N_1, AFTER 2^{ND} USE (20 Bags)									
Mark	EXTERNAL		INTERNAL		HEIGHT OF RIDGE			CHANGE IN HEIGHT AFTER USE	WEAR FACTOR L/bags
	RIDGE	GROOVE	RIDGE	GROOVE	EXTERNAL	INTERNAL	AVERAGE		
	a_e	b_e	a_i	b_i	$a_e - b_e = h_{e2}$	$a_i - b_i = h_{i2}$	$(h_{e2} + h_{i2})/2 = h_2$	$b = abs(h_{i2}-h_{i1})$	$W_a=b/20$
1	12.51	11.17	8.72	6.13	1.34	2.59	1.96	0.24	0.01
2	12.70	10.28	8.93	6.27	2.42	2.66	2.54	0.94	0.05
3	12.09	11.34	8.34	5.40	0.75	2.94	1.85	0.27	0.01
4	12.44	10.90	10.03	8.13	1.54	1.90	1.72	0.07	0.00
5	11.81	11.29	9.83	8.12	0.52	1.71	1.12	0.53	0.03
6	12.53	11.98	9.09	7.12	0.55	1.97	1.26	0.56	0.03
7	12.48	11.70	10.66	7.24	0.78	3.42	2.10	0.12	0.01
8	12.44	11.76	10.19	7.62	0.68	2.57	1.63	0.47	0.02
9	11.65	11.90	12.41	8.03	-0.25	4.38	2.07	0.65	0.03
10	10.56	11.13	10.32	8.77	-0.57	1.55	0.49	0.85	0.04
11	12.25	11.11	10.13	7.00	1.14	3.13	2.14	0.26	0.01
12	12.21	11.47	9.23	6.37	0.74	2.86	1.80	0.04	0.00
Average	**12.14**	**11.34**	**9.82**	**7.18**	**0.80**	**2.64**	**1.72**	**0.42**	**0.02**

Table 5: Parameters of Plate before and after use for Plate pair X_1X_2

(a) BLADE X_1, BEFORE 1^{ST} USE							
Mark	EXTERNAL		INTERNAL		HEIGHT OF RIDGE		
	RIDGE	GROOVE	RIDGE	GROOVE	EXTERNAL	INTERNAL	AVERAGE
	a_e	b_e	a_i	b_i	$a_e - b_e = h_{e1}$	$a_i - b_i = h_{i1}$	$h_1 = (h_{e1} + h_{i1})/2$
1	13.64	12.79	11.01	9.91	0.85	1.1	1.95
2	12.62	12.18	10.81	9.08	0.44	1.73	2.17
3	13.04	12.98	11.34	9.9	0.06	1.44	1.5
4	13.32	12.76	11.26	9.22	0.56	2.04	2.6
5	13.74	13.22	10.92	9.06	0.52	1.86	2.38
6	14.4	13.53	11.57	9.12	0.87	2.45	3.32
7	14.61	13.89	10.03	9.78	0.72	0.25	0.97
8	15.21	14.5	10.64	9.86	0.71	0.78	1.49
9	14.61	13.79	10.71	8.59	0.82	2.12	2.94
10	14.14	13.79	10.12	8.44	0.35	1.68	2.03
11	13.74	12.76	10.3	9.48	0.98	0.82	1.8
12	12.72	12.61	11.12	8.82	0.11	2.3	2.41
Average	**13.82**	**13.23**	**10.82**	**9.27**	**0.58**	**1.55**	**2.13**

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(b) BLADE X_1, AFTER 1^{ST} USE (21.5 Bags)									
Mark	EXTERNAL		INTERNAL		HEIGHT OF RIDGE			CHANGE IN HEIGHT AFTER USE	WEAR FACTOR L/bags
	RIDGE	GROOVE	RIDGE	GROOVE	EXTERNAL	INTERNAL	AVERAGE		
	a_e	b_e	a_i	b_i	$a_e - b_e = h_{e2}$	$a_i - b_i = h_{i2}$	$(h_{e2} + h_{i2})/2 = h_2$	$b = abs(h_{i2}-h_{i1})$	$W_a=b/21.5$
1	13.16	11.08	10.36	9.48	2.08	0.88	1.48	1.02	0.05
2	12.29	12.21	9.60	8.35	0.08	1.25	0.66	0.72	0.03
3	13.35	11.21	11.10	9.09	2.14	2.01	2.08	1.66	0.08
4	13.52	12.32	10.21	9.40	1.20	0.81	1.01	0.48	0.02
5	12.99	11.85	9.66	7.53	1.14	2.13	1.64	0.46	0.02
6	12.91	11.50	9.23	8.33	1.41	0.90	1.16	0.75	0.03
7	13.51	10.54	9.44	9.11	2.97	0.33	1.65	0.05	0.00
8	11.89	11.31	9.31	7.50	0.58	1.81	1.20	0.66	0.03
9	12.12	11.30	10.11	6.56	0.82	3.55	2.19	0.96	0.04
10	12.78	11.71	9.12	6.07	1.07	3.05	2.06	0.92	0.04
11	13.17	12.68	9.23	5.97	0.49	3.26	1.88	1.35	0.06
12	12.40	11.92	10.13	5.35	0.48	4.78	2.63	1.33	0.06
Average	**12.84**	**11.64**	**9.79**	**7.73**	**1.21**	**2.06**	**1.63**	**0.86**	**0.04**

From the results obtained the amount of average heat generated during the milling process can be summarised in Table 6. An average of 37.97 MJ of energy is wasted for grinding 1495 kg of corn. This wasted energy is part of the electrical input that was used only to overcome frictional force between the plates during the milling process. This energy is transferred to the milled product. In this way the milled product acts as a heat sink for the milling machine.

Table 6: Amount of heat generated by frictional energy between rubbing surfaces

ITEM	O_1O_2		
	1st	2nd	3rd
Bags	9.5	17.5	22
Energy Gen./(MJ)	23.3	44.93	60.96

ITEM	I_1I_2		
	1st	2nd	3rd
Bags	10	15.5	15
Energy Gen./(MJ)	20.52	39.88	35.71

ITEM	X_1X_2		
	1st	2nd	3rd
Bags	22	21.5	9.5
Energy Gen./(MJ)	54.69	50.83	28.93

ITEM	N_1N_2		
	1st	2nd	3rd
Bags	5	20	12
Energy Gen./(MJ)	12.82	51.99	31.19

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ITEM	Average
Bags	**14.95**
Energy Gen./(MJ)	**37.97**

Figure 2 to 5 show the height of ridges on a typical plate for specific ridges. Figures 2(a), 3(a), 4(a), and 5(a) demonstrates how the height changes with the mass of maize milled and Figures 2(b), 3(b), 4(b) and 5(b) show the average wear rate in terms of reduction in height of ridges per the mass of maize ground. From these same diagrams, it can also be demonstrated that the wear rate is not uniform across the ridges for a single plate because the change in height of the selected marked ridges after use was not constant. The changes in heights of the ridges of the plates were not only due to the wearing of the ridges but also due to the breaking off of the ridges hence it is very important to visually inspect corn milling machine plates for manufacturing defects before use.

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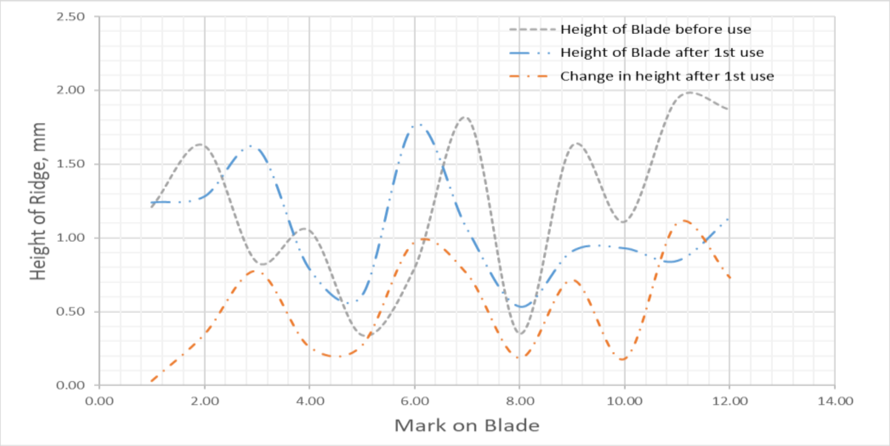
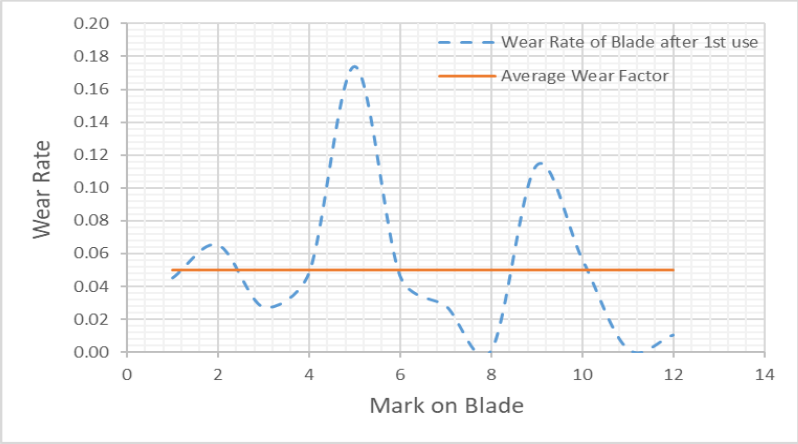


(a)



(b)

Figure 2: Wear Rate of Ridges on Plate for O

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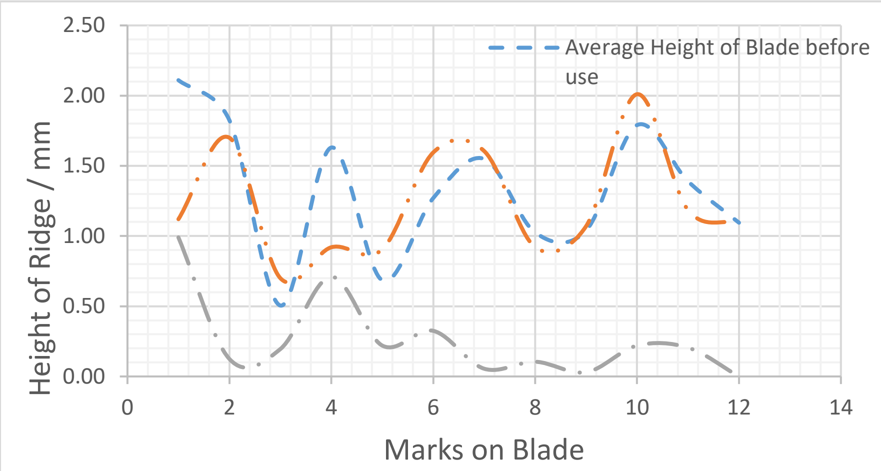
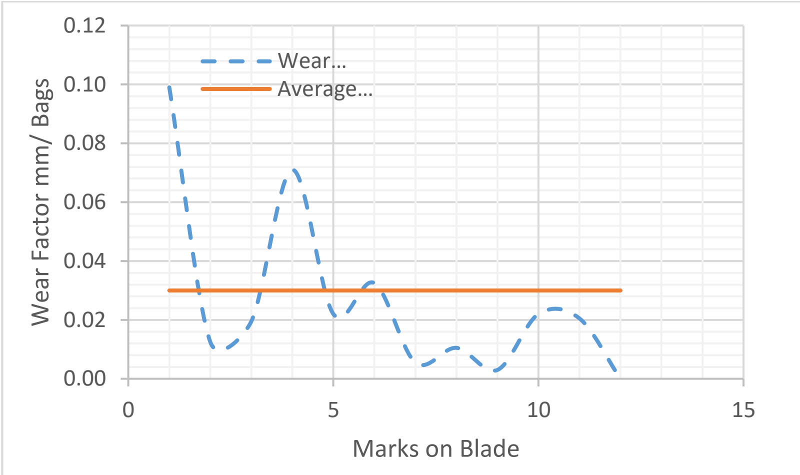


(a)



(b)

Figure 3: Wear Rate of Ridges on Plate for I

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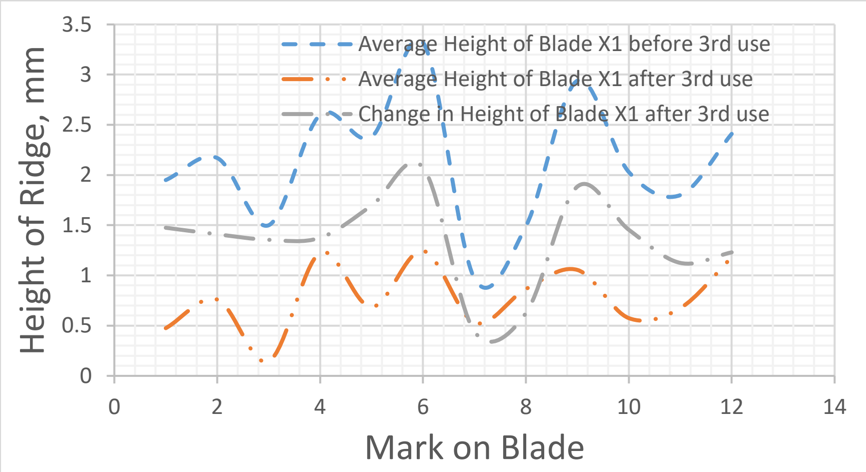
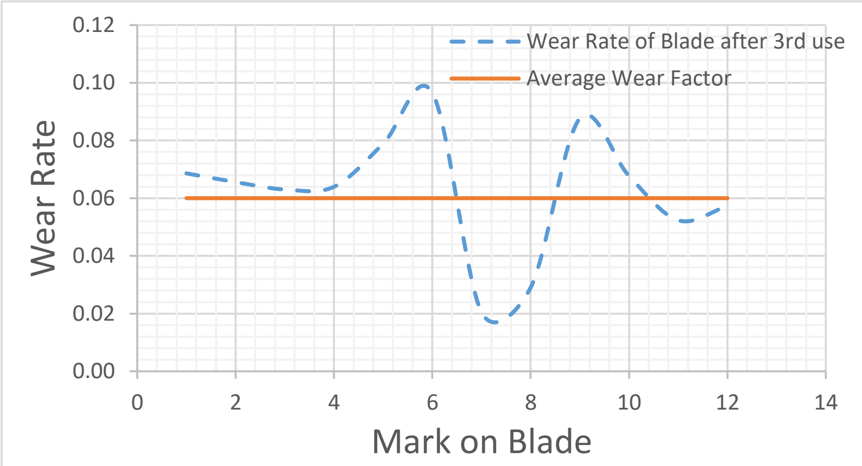


(a)



(b)

Figure 4: Wear Rate of Ridges on Plate for N

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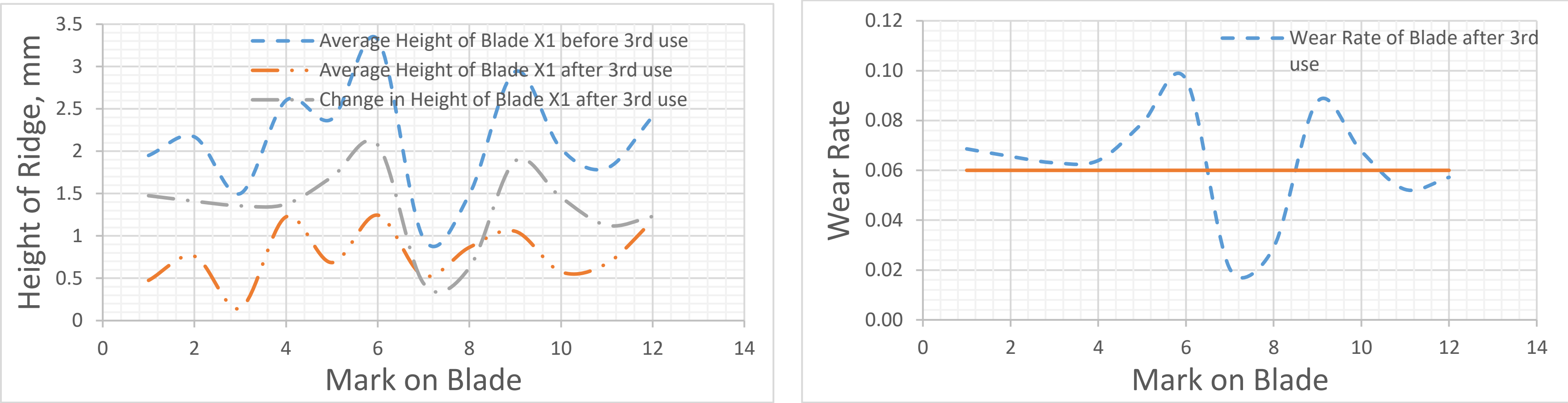

(a) (b)

Figure 5: Wear Rate of Ridges on Plate for X

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The wearing rates were also found to follow some thread as shown in Figure 6. At the beginning of the milling process, the wearing rate is at its peak and drop suddenly. The peak is as a result of some of the ridges breaking off from the sudden shock received from the rotation. This notable observation continuous until the ridges get as shorter as possible where the wearing then reduces as the rubbing surfaces have increased. The breaking off of the teeth is due to the slenderness and the small cross-section area.

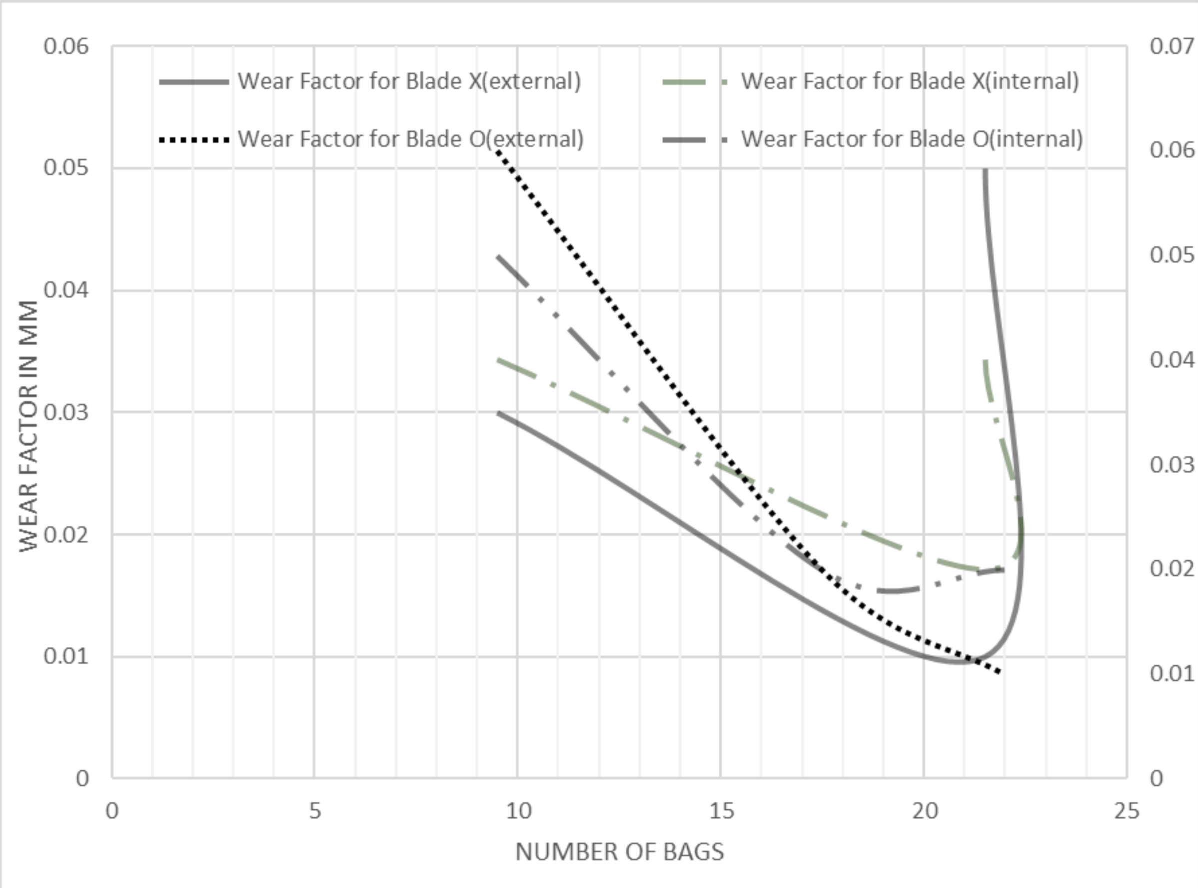

Figure 6: Wear Factor for the various stages

The range of attrition rates 0.01 to 0.05 mm/bag (i.e. Table 7) was observed for a range of 9.5 bags to 21.5 bags of corn. The slender the ridge the higher the rate of wear.

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Table 7: The attrition rate for the various plates

(a) Wear Factor for the various stages							
Plate	Item	External			Internal		
		1st	2nd	3rd	1st	2nd	3rd
I	Wear Factor Bags	0.03 10	0.02 15.5	0.04 15	0.04 10	0.03 15.5	0.01 15
N	Wear Factor Bags	0.02 5	0.02 20	0.03 12	0.04 5	0.02 20	0.01 12
O	Wear Factor Bags	0.06 9.5	0.02 17.5	0.01 22	0.05 9.5	0.02 17.5	0.02 22
X	Wear Factor Bags	0.05 21.5	0.01 21.5	0.03 9.5	0.04 21.5	0.02 21.5	0.04 9.5

CONCLUSION

The principal objective of this paper is to find the wearing or attrition rate for locally manufactured corn mill discs/plates for wet grinding to help corn millers to replace their plates at the right time to avoid the excessive wearing of the plates, reduce the amount of energy consumed and avoid the contamination of the processed maize.

An average of 37.97 MJ of energy is wasted as heat energy which is deposited into the milled product over time. In this way the by-product acts as a coolant.

The average heat deposited in the product causes an average rise in temperature of 19.13 to 21.68 ^{o}C.

It can be concluded that the amount of matter deposited as the plate wear is between 0.02 to 0.3 kg of metal for 9.5 bags to 21.5 bags of corn. This variation is also affected by the nature of the ridges on the plates.

Finally, for efficient use of the plate to reduce the amount of energy consumed on utility which is later deposited in the by-product, a pair of plates should be changed when 14 bags of corn is ground with an allowable attrition rate of 0.028 mm/bag.

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