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REDESIGN AND MANUFACTURE AN IMPACT CRUSHER HAMMER MILL USING ADVANCED IRON CASTING

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ABSTRACT

Through cooperation study between Agricultural Engineering Research Institute (AEnRI) and Central Metallurgical Research and Development Institute (CMRDI) farm machinery spare parts recommended to manufacture from an advanced iron casting called austempered Ductile Iron (ADI). The main objective of this research is to redesign a horizontal impact crusher hammer manufacture from (ADI) alloy by casting technology. Both of the original and the new manufactured hammers were tested in the Laboratory and in the Field. The final results indicated that the new hammer produced a highest percentage of fine crushed particles compare with original one. The wear rates were 0.037 g/h and 0.023 g/h for the original and new hammer respectively. This means that wear rate decreased by about 38% when replaced the redesigned hammer instead of the original one.

Keywords: Redesign, Crusher, ADI, manufacture.

1. INTRODUCTION

The crusher defends as the machine or the tool which designed and manufactured to reduce the large materials into smaller chunks. It could be considered as primary, secondary or fine crushers depending on the size reducing ratio. Crushers classified depending on the theory of the crushing acting as, Jaw crusher, conical crusher and impact crusher. The impact crusher type is widely used in agricultural applications, these crushers use the impact rather than the pressure to chuck and break the materials. The impact crusher classified to Horizontal impact crusher (HIC) and vertical impact crusher (VIC), based on the type of arrangement of the impact rotor and shaft. **Khurmi and Gupta (2005)** described the horizontal impact crusher as the crusher's break the materials by impacting it with hammers fixed upon the outer edge of spinning rotor. The rotor shaft is aligned along the horizontal axis. These types of crushers have a reduction ratio ranged from 10:1 to 25: 1. **Deepak (2008)** stated that in an impact crusher the breakage take place in less time than the conical or Jaw crusher. The nature and magnitude of force dissipated due to impact breakage is different from that of the relative slow breaking occurs by compression or shear in other type of crushers. **Nikolov (2004)** stated a general scheme of breakage process as shown in Figure 1. He reported that, the impact breakage takes place in a very few time and results into a dynamic crack propagation that leads to much faster failure of particles.

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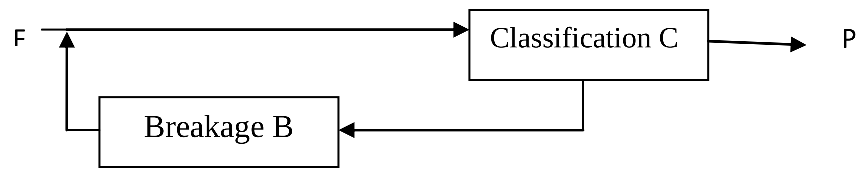

Figure (1): Breaking process

where:

F: feed vector B: breakage operator
P: product vector C: probability of breakage of each particle size

In this study there was no feedback as the crusher used a single breaking process which it corresponded with the distribution model by **Csoke and Racz (1998)** it was assumed that the particles entered crushers has a single breakage process and there is no feedback between the classification and the breakage function while the breakage process due to breakage occurred by the impact with hammers. Also, fragmentation occurred due to particle collisions. **Jarmo (2006)** indicated that, for a good design and performance for a crusher, some basic factors should be taken into account like; wise selection of the hammer material, optimum number of hammers, rotor speed ,and input materials properties. **Chawdhury (2007)** stated that, the average life of the hammers in the impact crusher depends on the hardness of the materials, kind of deportation it is being used, usage of the crusher and the kinetics rotation of the hammers. The hammer manufactured from steel average life is from 50 to 60 working hours, if it used with a hard solid materials such as rocks and stones. On the other hand, it reached to (1200 – 1500) hours if used with agricultural grain and residuals materials. Hammers blow bars has different shapes such as (I, T, S) section, cylindrical bars, rectangular bars and square bars. The shape of hammers affected directly on the impacting capacity and the crusher strength. Most of the hammers are made from manganese steel .**Harding (2002)** reported that Austempered Ductile Iron (ADI) is a restively a new engineering material with exceptional combination of strength ductility, wear resistance, fatigue strength and able to machine. This material has marked potential for numerous applications in automotive, agricultural, earthmoving, mining constructions and military applications. Engineers and designers have learned that ductile iron can be easily cast into complex shapes by subsequently Austempering these casings, they could exhibit strength to weight ratio comparable to heat treated steel or aluminum. This allows the designers to create one piece designs that might have been previously assembled from multiple forgings casting, extrusions, welding or stampings. **(Nofal, 2013). Keough, et. al. (2010)** stated that many types of wheeled agricultural and construction equipments are being converted into rubber tracks for increased its versatile and to lower its weight, cost and soil compaction. In one application a one piece ADI main drive wheel replaced an 84 (eighty four) pieces welded steel. Created a one piece ADI design provided a lower cost, more durability and the wheel reliability was improved by eliminating the variability in cutting, stamping, drilling, bolting and welding the components together. The objective of this study is to redesign a horizontal impact crusher hammer manufactured from the ADI alloy by casting. Both original and the ADI hammers were laboratory tested and field evaluated on different types of crushing materials and different grades of Austempered Ductile Iron (ADI). According to the casting technology, the shape of the hammer redesign to be suitable to manufacture by casting instead of welded steel bars.

2. Data and methodology

2.1: Current crusher:

The selected crusher is one of the common used by the small farm holders. The crusher was a small horizontal shaft impact crusher. The crusher total feed rate was 115 kg/hour, output was100 kg/hour that. The local machine powered with 1.2 kW Italian made electrical motor .The impact crusher rotor was rotate in one direction using a belt connected with the motor via two pulleys. The materials fed to crushing chamber through feed gate. The material moved repeatedly in the crushing chamber containing hammer mill and screen which required to crush the materials. The screen sieves diameters ranged from 3.7 to 7.5 mm. Figure (2) shows a schematic of crusher and its parts. Also Figure (3) shown the original hammer mill that consisted of five bars steal formed by welding .

2.2: Primary experiment

Initial experiment has been done to evaluate the machine efficiency using the original hammer. Different materials were used such as Maize grain as a crop, Corn stalk as crop residue and plastic tube as municipal waste. The second step of that initial experiment includes a laboratory tests to indicate the micro structure, chemical composition and the hardness of the original hammer. The laboratory tests and analysis was done at Central Metallurgical Research and Development Institute (CMRDI), Cairo. Egypt.

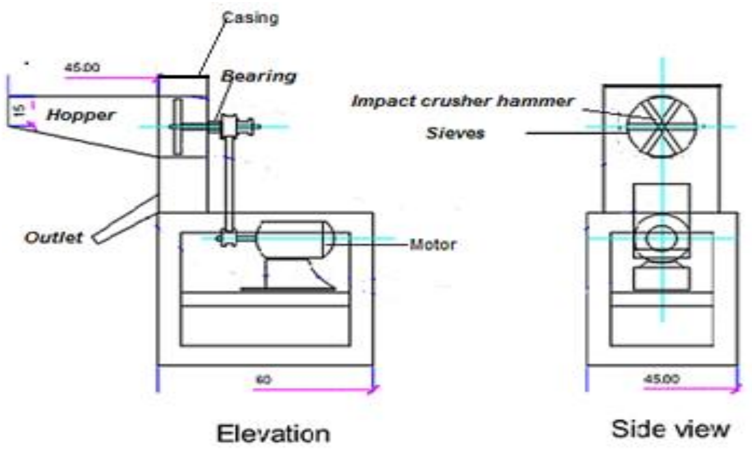

Figure (2): schematic of crusher

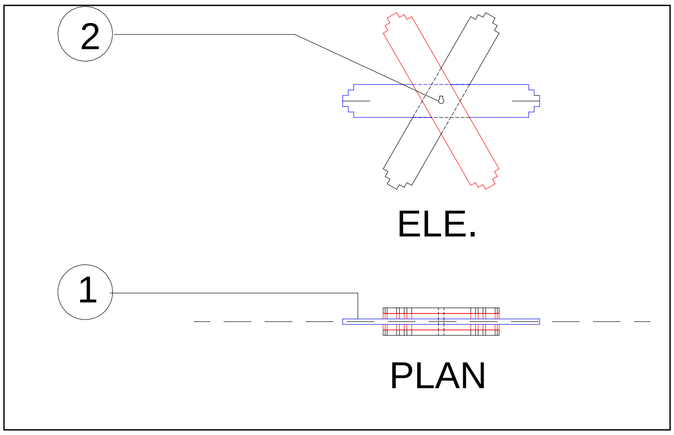

Figure (3): Original hammer mill

1-Hammer plat 2- *Hammer hub*

2.3: Redesign parameters:

The original hammer mill dimensions were not suitable to forming by using the casting methods. To product such a hammer suitable to form from Austempered Ductile Iron (ADI) a new design should be carried out taken into account the

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following parameters, Selecting of the proper material and hammer dimensions. Set of the optimum shape and rotor speed of the hammer. Studding the crushed materials some properties such as density, (strength or hardness), and moisture content. Also, study the Crusher performance at different rotational speeds under required conditions.

2.4: Impact energy required:-

The rotor mass is much greater than mass of single particle in the feed. Linear velocity of the crushing hammer before impact is more considered than the particles velocity, and then kinetic Energy (KE) of particles is negligible.

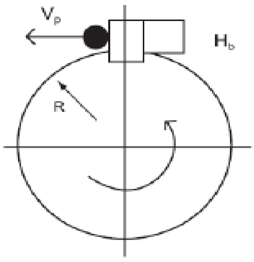

Figure (4): Particle during the rotor with horizontal hammer crusher

Assumed that most of the particles enter in the medium part of the impact area of the hammer, consider of linear movement before and after impact the mass energy (Em) given by the following equation:-

$E_m = 0.5\,(R + 0.5H)^2 + \omega^2$ ------- (1) (Nilolov 2004)

where:-

R: Rotor radius, mm

H: Height of the impact surface, mm

ω: Rotor velocity (rpm)

2.5 :Impact bending stress:

To insure the new design of the hammer is safe in this experiment conditions ,the maximum allowance moment (M_a) should be greater than or at less equal the actual maximum moment (M_{max}). The two moments were calculated according to the following equations:-

Max. moment (M_{max}) = p* H_hw/2-------------(2) (**Khurmi and Gupta 2005**)

P= w (h+y)

where:

P: is the equivalent static force N.mm

w: impact force N

h: height of fall material mm

y: defalcation mm

Max. Allowable moment (M_a) =$C_s LZ^2$*2/12------ (3) (**Khurmi and Gupta 2005**)

where:

Cs: allowable stress N/mm^2

L: Length of bar mm

Z: Thickness of bar mm

2.6: Austempered Ductile Iron (ADI) allay:

As results of a collaboration project between Agricultural Engineering Research Institute and Central Metallurgical Research and Development Institute, it is produced several kind of austempered ductile Iron and also carbide austempered ductile Iron. The two alloys are easy to cast in different shapes and able to be formed to several spare parts of machine. Table (1) showed the chemical properties of different types of the two alloys.

Table: 1. the chemical properties of the ADI and CADI.

Alloys	C	Si	Mn	Cu	Mo	Cr
ADI 375	3.6	2.5	0.35	0.5	0.28	-
ADI275	3.6	2.5	0.35	0.5	0.28	-
CADI.1	3.5	2.5	0.37	0.53	0.31	0.98
CADI.2	3.5	2.5	0.37	0.53	0.31	1.89

2. 7 Testing Procedures of the performance evaluation

The modified machine was tested on corn grain, corn stalks and plastic pipes, while the testing apparatus were stop watch, weighing balance and sets of sieves. Two kilograms of the materials sample was fed into the crushing chamber of the machine through the feed hopper. The time taken to crush the sample i.e. the sample to fully discharge was noted. The weight of the crushed sample was taken after which the crushed sample was taken for a sieve analysis to separate the finely crushed materials from the coarsely crushed sample. The weight of both the fine samples and that of the coarse samples were recorded according to the sieve sizes. The process was repeated for samples weight of 4kg and 6kg respectively. The process of crushing the weights 2kg, 4kg and 6kg were taken as the trials and one sieve analysis is presented here from all the trials. This procedure was used for both material used as presented in the results for original and redesign using the following equation according to ***PHILIPPINE NATIONAL STANDARD PNS/PAES 217:2005 (PAES published 2004) ICS 65.060 .***

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$$\text{Crushing effciency} = \frac{\text{Mass of out put material}}{\text{Mass of in put material}}$$

$$\text{Losses } = \frac{M_b - M_a}{M_b}$$

Where

M_b = Mass before grinding (kg)

M_a = Mass after grinding (kg)

3. RESULTS AND DISCUSSION

3.1 Properties of the original and new hammer:

The original hammer Figure (5) was tested and analysis in the CMRDI laboratory and it found has the following specifications:-

1-Sample – ID: Crusher Hammer

2-Sample Material:

Heat Treatable Carbon Steel

DIN No: 20Mn5

Mat No: 1.1133

Figure (5):: The original hammer

3.2Chemical Analysis:

Table: 2. the average analysis of three sparks detected

Element	C	Si	Mn	P	S	Cr	Ni	Al	Cu	W	Fe
%	0.098	0.379	1.2	0.012	0.004	0.1481	0.092	0.049	0.143	0.015	97.43

3.3 Alloy Specifications:

3.3.1 Metallographic Examination

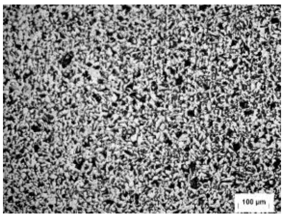

Figure (6): microstructure of the original hammer, Magnification 100x

3.3.2 Average Hardness Value:235HV

3.4 New shape hammer:

Pre samples of the new hammers were manufactured in the casting unit at CMRDI. From the four produced alloys which presented before the hammers were mad from the ADI-375. That type of iron was selected for its properties which height wear resistance as well as higher impact tolerance. After manufacture, each hammer was rotating balanced to decrease vibration at rotor speeds of 1000, 1500 and 2000 r.p.m. Also, the hammers were tested to determine the wear rate and the hardness at the laboratory of CMRDI . They were 0.04 gm and 420 HV respectively. While it was 0.09 gm and 235 HV for the original hammer under the same test conditions using the Tribometer. The results indicated that weight losses decreased by about 55% while the hardness was greater by 98% for the new hammer compared with the original. The final produced new hammer was manufacture using the alloy ADI 375 depending on the needed performance related to theoretical calculation design and the work conations. The new replaced hammer was produced by casting. By that technology the new hammer created in one piece designs replaced multiple parts and welded of the exceed hammer as shown in figure (7).

3.5 Impact energy required:

Impact energy calculated per unite mass according to Equation1, considering the conservation of liner moment before and after the impact energy mass which is the required impact energy was 0.61 hp where the rotor radius equal 12.5 cm, height of impact surface equal 25 cm and the rotor velocity was 1500 rpm.

3.6 Design parameters calculation:

According to the design parameters equations 2 and 3 the maximum and the allowable moment was calculated depending on the ADI material properties and alloy structure where the bulk density of the materials consider 89 g/cm3, number of bars were 6 hammer diameter 25 cm, hammer head width 35mm and hammer head thickness 25 mm . At that work conditions the allowable moment was 9.1 N/mm2 while the maximum moment was equal 3.47 N/ mm2. Since the Actual moment greater than the maximum moment (M al> M max) the design is safe using that materials and that dimensions.

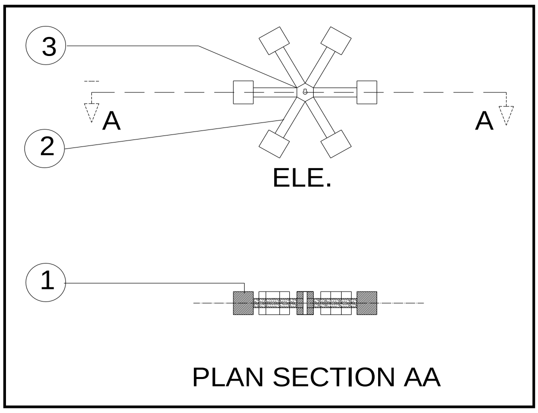

Figure (7): The redesigned hammer

1-hammer 2-hammer rod 3-hammer hub

3.7 Primary Field testing

Both of the original and new hammers were fixed in the crusher machine. The crusher machinery has been feeding by different materials which were available in the test site. The feeding materials were, corn grain, corn stalks, and plastic tubes. The primary performance evaluation includes, crusher feed rate, productivity (output materials), crushing and materials classifications

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Figure (8): The machine during experiments

Table: 3. Hammers productivity

Materials	Original hammer		New hammer	
	Feed rate kg/h	Output kg/h	Feed rate kg/h	Output kg/h
Corn grain	**128**	**117.4**	**128**	**120.9**
Corn stalks	85	78	85	84
Plastic tube			45	44.5

Table: 4. Classified of output materials

hammers	Materials	Particles size mm					
		0.6	1	1.4	2.5	3.75	>3.75
Original	Corn grain	19	17	22	41	1	
	Corn stalks	0	0	40.8	33	8	18.2
	Plastic tube						
New hammer	Corn grain	21	18	24	37	0	
	Corn stalks	4.9	10.3	72	8		
	Plastic tube	0	1.9	12.5	12.4	64.1	1.8

Figure (9): Crusher materials distribution

Data presented in table 4 and figure 9 indicated the particles size distribution output from the crushers. Results indicated for the corn grain the height percentage generally found at the size 2.5mm with using the original and new hammer. The new hammer produced a highest percentage of the fine particles size about 63 % while it was 58 % when using the original one. The particles size distributions ratio after cutting and crushing the corn stalks were 72% at size 2.5 mm using the new hammer while it was decreased to 40.8% for the same size when using the original hammer. Finally, the new hammer shape tested with some plastic tube to evaluate the hardness and durability of the ADI alloys as well as evaluate the new hammer performance. The results indicated that the new hammer able easily to cut and crush the plastic tube and the crushing size distributions were 0.0, 1.9, 12.5, 12.4, 64.1, and 1.8 % at size 0.6, 1, 1.4, 2.5, 3.75 and >3.75 mm respectively. That trial was done to crush the plastic tube introduce a recommended idea to recycle the plastics tubes and irrigation net components. The wear losses rates were determined depending on the working hours and the total weight losses as presented in table 5.

3.7 Final crusher performance evaluation

Two materials "maize and bean" were used to determine and evaluate the performance of the crusher depending of the procedures presented in 2.8. This procedure was used for both of the original and redesign using the following equation.

Table 5 . Hammer mill test results using maize before redesign

Trials	Mass of maize before Crushed (kg)	Mass of maize after Crushed (g)	Time taken (min)
1	2	1840	1.1
2	2	1860	1.05
3	2	1866	1..02
4	2	1854	0.98
Ave.	2	1855	1.04
1	4	3700	1.85
2	4	3760	1.95
3	4	3756	2
4	4	3760	2.08
Ave.	4	3744	1.97
1	6	5660	3
2	6	5595	2.8
3	6	5600	2.8
4	6	5608	2.87
Ave.	6	5615	2.87

Table 6. Hammer mill test results using maize after redesign

Trials	Mass of maize before Crushed (kg)	Mass of maize after Crushed (g)	Time taken (min)
1	2	1860	1.1
2	2	1859	0.97
3	2	1856	1.06
4	2	1861	0.93
Ave.	2	1859	1
1	4	3755	1.85
2	4	3735	1.95
3	4	3740	2
4	4	3754	1.92
Ave.	4	3746	1.93
1	6	5620	2.82
2	6	5669	2.75
3	6	5675	2.8
4	6	5680	2.87
Ave.	6	5661	2.81

According to the productivity Tables 5 and 6 it was observed that the redesigned impact crusher hammer mill given more crushing capacity of material than the original impact crusher hammer mill and produced finer particles compared to that of original impact crusher hammer mill, higher efficiency and lesser losses at different feed rat as shown in table. Crushing capacity for original impact crusher hammer mill 106.7, 113.8 and 117.4 .kg/h for crushing material weights 2kg, 4kg and 6kg respectively . Redesigned impact crusher hammer mill crushing capacity where111.5, 114.1and 120.9 kg/h material weights 2kg, 4kg and 6kg respectively. Crushing efficiency for original impact crusher hammer mill ranged from92.8% to 93.6 % compare with 93.7 % to 94.4 % for redesigned impact crusher hammer mill.

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Crushing losses for original impact crusher hammer mill ranged from 6.42% to 7.25 % compare with 5.6% to 7% for redesigned impact crusher hammer mill.

Table 7. Sieve Analysis of Crushed maize with original Machine

Nominal Aperture (µm)	RETAINED				PASSED	
	Weight (g)	Cumulative Weight (g)	Percent Weight	Percent Cumulative Weight	Cumulative Weight (g)	Percent Cumulative Weight
3750	23	23	1%	1%	1827	58%
2500	765	788	41%	42%	1062	35%
1400	415	1203	22%	65%	647	18%
1000	312	1515	17%	82%	335	1%
600	340	1855	18%	100%	23	0%

Nominal Aperture (µm)	RETAINED				PASSED	
	Weight (g)	Cumulative Weight (g)	Percent Weight	Percent Cumulative Weight	Cumulative Weight (g)	Percent Cumulative Weight
3750	39	39	1%	1%	3744	61%
2500	1470	1509	39%	40%	2274	38%
1400	860	2369	23%	63%	1414	20%
1000	660	3029	18%	81%	754	1%
600	715	3744	19%	100%	39	0%

Nominal aperture (µm)	RETAINED				PASSED	
	Weight (g)	Cumulative weight (g)	Percent weight	Percent cumulative weight	Cumulative weight (g)	Percent cumulative weight
3750	45	45	1%	1%	5609	60%
2500	2230	2275	40%	41%	3379	37%
1400	1290	3565	23%	63%	2089	20%
1000	975	4540	17%	81%	1114	1%
600	1075	5615	19%	100%	39	0%

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Table 8. Sieve Analysis of Crushed maize with redesign Machine

Nominal Aperture (µm)	RETAINED				PASSED	
	Weight (g)	Cumulative Weight (g)	Percent Weight	Percent Cumulative Weight	Cumulative Weight (g)	Percent Cumulative Weight
3750	12	12	1%	1%	1838	59%
2500	750	762	40%	41%	1088	37%
1400	405	1167	22%	63%	683	19%
1000	330	1497	18%	81%	353	1%
600	362	1859	19%	100%	23	0%

Nominal Aperture (µm)	RETAINED				PASSED	
	Weight (g)	Cumulative Weight (g)	Percent Weight	Percent Cumulative Weight	Cumulative Weight (g)	Percent Cumulative Weight
3750	21	21	1%	1%	3764	62%
2500	1425	1446	38%	39%	2339	39%
1400	875	2321	23%	62%	1464	21%
1000	680	3001	18%	80%	784	1%
600	745	3746	20%	100%	39	0%

Nominal Aperture (µm)	RETAINED				PASSED	
	Weight (g)	Cumulative Weight (g)	Percent Weight	Percent Cumulative Weight	Cumulative Weight (g)	Percent Cumulative Weight
3750	32	21	0%	0%	5679	62%
2500	2170	2191	38%	39%	3509	39%
1400	1275	3466	23%	61%	2234	21%
1000	1030	4496	18%	79%	1204	1%
600	1165	5661	21%	100%	39	0%

According to the sieve analysis in Table 7 and 8, it was observed that the redesigned impact crusher hammer mill takes lesser time to crush a particular quantity of material than the original impact crusher hammer mill and produced finer

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particles compared to that of original impact crusher hammer mill. There are so many factors that could be responsible for this feed rate and the geometric of the impact crusher shape . The percent of cumulative weight passed/percent cumulative retained against nominal aperture as it was confirmed that more coarse particles gotten from the original impact crusher compared to more fine particles gotten from the redesigned fabricated impact crusher. Also, the graph of percent cumulative weight passed/percent cumulative retained against nominal aperture when the maize was crushed with the fabricated machine about 2200 µm aperture size, about forty percent cumulative weight of the crushed samples have passed, while sixty percent cumulative weight of the crushed samples are still retained. It is confirmed that the fabricated impact crusher would be a better one when different sizes is highly desired for a particular crushing operation of the same material . All these now gives the final difference between the original impact crusher and the fabricated impact crusher, which are, the original impact crusher is a suitable one when fineness is needed in terms of sizes of crushed material of a particular material, but with low crushing rate, while the fabricated machine has higher crushing rate with different sizes of the same material.

3.8 Wear rate testing

A weight loss from the hammer was the wear indicator. Wear measuring have been done by replaced the hammers every 30 working hours and weight it. The field test was running for 150 hours the final average results tabulated in Table 9.

Table 9. Wear rate of the hammers

Working hours / Hammers type	Weight losses gm					Wear rate gm/hour
	30	60	90	120	150	
Original hammer	1.24	3.6	4.1	4.9	5.6	0.037
New hammer	0.81	2.1	2.9	3.1	3.5	0.023

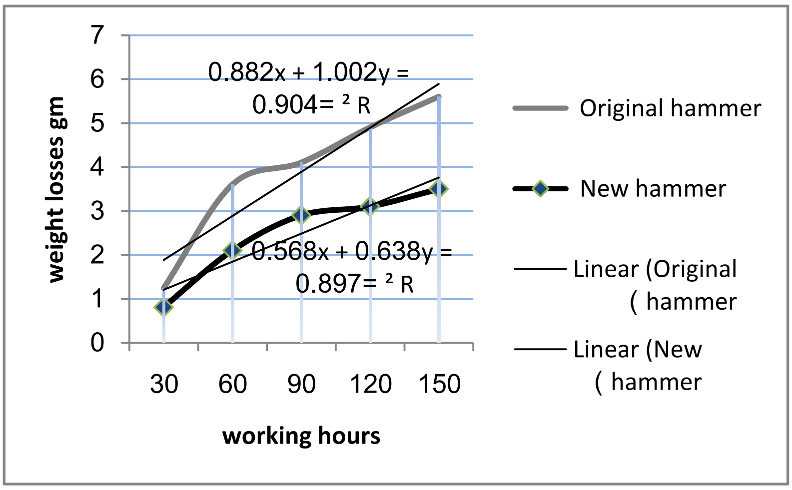

Fig. 10: hammers wear values

Results presented in table 9 and figure 10 shown the weight losses during the operation hours for both of the new and original hammers. The wear rate which measured by determined the weight losses were 0.037 g/h and 0.023 g/h for the original and new hammer respectively. At the end of the experiment after 150 working hours the total weight losses were 5.6 gm for the original hammer and 3.5 gm for the new hammer made from the ADI. That result observed there is a decreasing in wear by about 2.1 gm at the end of experiment. The results indicated also the wear rate decreased by about 38% when replaced the new hammer instead of the original one. According to the trend equation after 1000 working hours the predicted weight losses will be about 1002.8 g (by wear rate = 1.0 g/h) and 638.5 g (by wear rate = 0.6 g/h) that results approved the experimental results in a general trend as it is indicated that the wear rate generally decreased by about 40% when replaced the original hammer by the new one.

4. Conclusion

The impact crusher was subjected to test using available material such as Maize, Corn stalks and Plastic tube with masses 2kg, 4kg and 6kg for each material. The output of the redesigned impact crusher was satisfactory. Also, the sieve analysis to ascertain the crushability rate of the redesigned impact crusher was satisfactory. Sequel to this fact, the redesigned impact crusher appears to be capable of crushing other material such as limestone with a meaningful crushing capacity. Several kind of farm machinery parts have been produced from austempered ductile Iron and also carbidic austermpered ductile Iron. The two alloys are easy to cast in different shapes and able to be manufactured to several spare parts of machine. A new hammers were manufactured from the ADI-375 which have height wear resistance as well as higher impact tolerance. After manufacture, each hammer was tested by the balance equipment in rotor speed 1000, 1500, 2000 rpm. The hammers tested in the laboratory to determine the wear rate and the hardness which were 0.04 gm and 420 HV respectively. While it was 0.09 gm and 235 HV for the original hammer under the same test conditions using the Tribometer. The original and the new hammers were fixed in a crusher machine which feeding by different materials likewise corn grain, corn stalks, and plastic tubes. The new hammer produced a highest percentage of the fine particles size about 67.8% while it was 36.2% when using the original one. The particles size of the crushing corn stalks were 72% at size 3 mm using the new hammer while it was decreased to 40.8% for the same size when using the original hammer. The new hammer able easily to cut and crush the plastic tube and the heights crushing size was 64.1at sieve diameter 15 mm. The wear rates were 0.037 g/h and 0.023 g/h for the original and new hammer respectively. It is recommended to use the ADI and CADI alloys to mad a several machine parts for it is high performance and specification, save the cost, increase the working life, and foreign currency saving by reduce the export. .

5. ACKNOWLEDGMENTS

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