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DESIGN, FABRICATION AND TESTING OF A LABORATORY SIZE HAMMER MILL

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ABSTRACT: *The laboratory size hammer mill was fabricated from locally available materials for crushing of minerals such as calcite, dolomite, limestone, granite and other materials of medium hardness. The crushing process is achieved by the use of a set of hammers in a crushing chamber which beats the mineral feeds into smaller particles small enough to pass through the aperture of the replaceable sieve positioned beneath the crushing chamber. The size aimed depends on the aperture of the replaceable screen. Based on the theoretical design, it was found that the main shaft speed of 913.5 rpm transmitted by a belt drive from a three horse power electric motor is suitable to crush effectively. A comparison of the products of the newly fabricated machine with those of a standard Denver laboratory jaw crusher shows that the crushing rate of the new machine is higher, though the standard machine produces coarse products. The results however indicated that the new machine can perform better in terms of products with improved design. The machine is portable, design to be power operated.*

KEYWORDS: **Design, Fabrication, Laboratory Size Hammer Mill**

INTRODUCTION

Crushing is an integral part of the comminution flow sheet for mineral processing operations and is critical for the preparation of ore for downstream processing. The selection of the right crushing equipment for a specific purpose is influenced by many factors some of which are downstream of the crushing plant. Mineral processing is a complex operation. The principal procedure is crushing, that is the size reduction in the size of the fragmented rocks so that it can be rendered to another stage for further processing. In ancient time, the mineral were crushed between two stones or the use of metals with stones, but the invention of modern systems employing steel materials such as hammers mill has revolutionize the processing of minerals in a small scale and large scale capacity.

There are various types of machines generally used for size reduction of materials. These are Gyratory crusher. Jaw crusher, Ball mill, Burr mill and many others. Thus, of all the crushing machines available, the Gyratory crusher, jaw crushers and the hammer mill are the most widely used in mineral processing industries because of its desirable characteristics which include ability to handle a wide variety of raw materials, ability to handle hard stray objects and its robustness. In the big mining industry, four processes are adopted for continuous size reduction; these are the primary, secondary, tertiary and the quaternary crushing operations (Dance 2001). There are four basic ways of reducing the size of materials in the mineral processing industry, these are impact, attrition, shear or compression and most crushers employs a combination of these crushing methods (Brennal et al., 1969).

Crushing operation is becoming very popular in the Nigerian mineral industry, because of the growing awareness of the minerals deposits that abound in the country and the importance of these mineral resources in the economic development of the country. The mining industry has been unable to meet up with the demand of this manufacturing and construction companies due to low supply of their demand as a result of no small scale mining firm to supplement the existing large scale mining firm.

MATERIALS AND METHODS

The general design was based on the process of allowing a strong and durable metallic object inform of hammers to beat any material that obstruct its way during operation, thereby resulting into breakage of the material which can also be referred to as size reduction in comminution operation. This usually occurs in an enclosed chamber called the crushing chamber. The physical and mechanical properties of the mineral to be crushed were studied as this would help immensely in the design of various components of the rotor. The engineering properties and some other parameters are the main factors considered before design of the machine.

Theoretical Design Consideration

The design was carried out on the basics of the safety of the operator. Some other major hazards which may arise in the course of crushing were properly put into consideration. The deflection of the hammers while in operation was also considered in the design. Swinging instead of stiff hammers was used to avoid the rotor or the hammers from getting stocked in case a hammer comes in contact with a material it cannot break at first impact.

Design theories and Calculations

Determination of Shaft Speed

To calculate the shaft speed the following parameters are used.

$$\frac{D_1}{D_2} = \frac{N_2}{N_1} \qquad \textbf{Spolt, 1988} \qquad (1)$$

Where

N_1 = revolution of the smaller pulley, rpm

N_2 = revolution of the larger pulley rpm

D_1 = diameter of smaller pulley, mm

D_2 = diameter of larger pulley, mm

This shaft speed is only obtained when there is no slip condition of the belt over the pulley. When slip and creep condition is present, the value (913.5rpm) is reduced by 4% (Spolt, 1988).

Determination of Nominal Length of the Belt

$$L = 2C + \frac{\pi}{2}(D_1 + D_2) + \left(\frac{D_1 - D2}{4C}\right)^2$$ **Patton 1980** (2)

Where,
L = Length of the belt, mm
C = Centre distance between larger pulley and the smaller one, mm
Centre distance minimum, C_{min} was calculated using:

$$C_{min} = 0.55\,(D_1 + D_2) + T$$ **Patton, 1980** (3)

And Centre distance maximum:

$$C_{max} = 2\,(D_1 + D_2)$$ **Patton, 1980** (4)

T = Nominal belt thickness
D_1 = Larger pulley diameter
D_2 = Smaller pulley diameter

Determination of Belt Contact angle

The belt contact angle is given by equation

$$Sin^{-1}\beta = \frac{(R - r)}{C}$$ **Hall *et al.,1980*** (5)

Where,
R = radius of the large pulley, mm
r = radius of the smaller pulley, mm

Determination of the Belt Tension

$$T_2 = \frac{(T_1 - MV_2)}{\exp\left[\dfrac{\mu\alpha}{Sin\frac{1}{2}\theta}\right]}$$ **Hall *et. al.,1980*** (6)

T_1 = SA
Where
S = the maximum permissible belt stress, MN/m^2
A = Area of belt

Determination of the Torque and Power Transmitted for the Shaft

Power = $(T_1 - T_2)V$,
$T_r = (T_1 - T_2)R$, N
Where,

Tr = Resultant Torque
T_1 & T_2 = Tension in the belt, N
R = Radius of bigger pulley, mm

Determination of Hammer Weight

$W_h = m_n g$ **Patton 1980** (7)

Material = Mild Steel

Density = $7.85 g/cm^3$ (**Patton 1980**)

$$\text{Density} = \frac{\text{Mass}}{\text{Volume}}, \ kg/m^3$$ **Patton 1980** (8)

Weight of each hammer = 0.24 kg

Number of hammers = 12

Determination of the Centrifugal Force exerted by the Hammer

$F = \omega r \sqrt{m s}$ **Flavel, 1981** (9)

Where

ω = the rotational speed of the rotor, radians/seconds

m = mass of the ore, kg

r = radius of the rotor, m

s = the ore stiffness to breakage, N/m

Determination of Hammer Shaft Diameter

$$\sigma_s(\text{allowable}) = \frac{M_b Y_{max}}{I}$$

$$\frac{I}{Y_{max}} = Z = \sigma_s = \frac{M_b}{Z}$$ **Spolt, 1988** (10)

Where

Y_{max} = Distance from neutral axis to outer fibers

I = Moment of inertia

Z = Section modulus

For solid round bar

$$I = \frac{\pi d^4}{64}$$ **Spolt, 1988** (11)

$$Z = \frac{\pi d^3}{32}$$ **Spolt, 1988** (12)

Twisting of the shaft is neglible from the torsion rigidly calculation

Determination of the Shaft Diameter

The ASME code equation for solid shaft having little or no axial loading is

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$$d^3 = \frac{16}{\pi\sigma_s}\sqrt{(K_b M_b)^2 + (K_t M_t)^2} \qquad \textbf{Hall } \textbf{\textit{et al.}} \qquad (13)$$

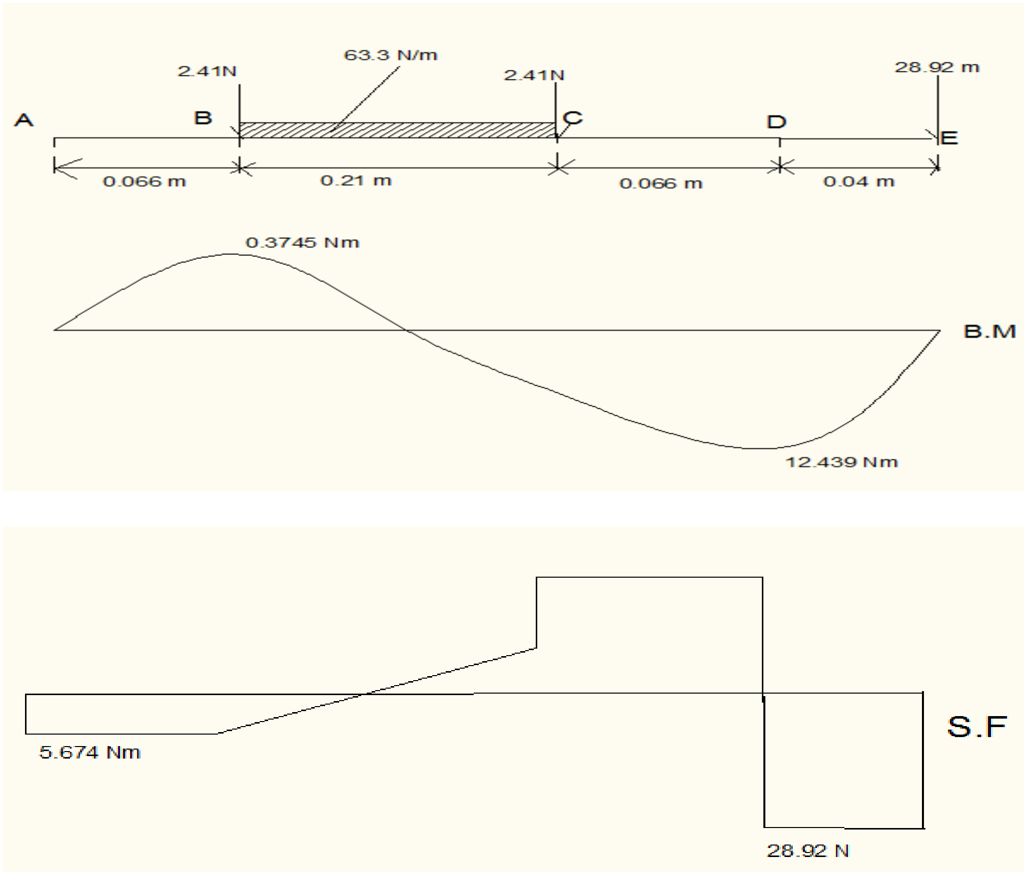

Figure 1: Shear force and bending moment Diagrams

Testing Procedures

The materials used for testing of the machine can be divided into two, which are the minerals and the testing apparatus. The minerals are dolomite and granite, while the testing apparatus are stop watch, weighing balance and sets of sieves. 2kg of dolomite 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 of weight 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 minerals used as presented in the results.

The same testing procedure used for the fabricated machine was also used for a standard crushing machine, since it is part of the objective to fabricate a hammer mill and compare the efficiency with a standard machine available.

RESULTS AND DISCUSSION

According to the sieve analysis table, it was observed that the fabricated hammer mill takes lesser time to crush a particular quantity of material than the standard machine and produced finer particles compared to that of standard machine. There are so many factors that could be responsible for this which include the gape of the machine which determines the feed rate, the set which determines the size of the output materials, the speed of the electric motor installed and the age of the machine.

In the graph of percent cumulative weight passed/percent cumulative retained against nominal aperture as presented in Figure 3 and Figure 4, it was confirmed that the percent cumulative passed graph did not intercept the percent cumulative retained when granite was crushed with standard machines. This is as a result of more coarse particles gotten from the standard machines compared to more fine particles gotten from the fabricated machine. Also, the graph of percent cumulative weight passed/percent cumulative retained against nominal aperture when the granite and dolomite were crushed with the fabricated machine as presented in Figure 1 and Figure 2 indicated that at about 1350 µm aperture size, fifty percent cumulative weight of the crushed samples have passed, while fifty percent cumulative weight of the crushed samples are still retained.

From the energy consumption analysis using Bonds' equation, it was confirmed that higher energy was consumed by the fabricated hammer mill while crushing granite and dolomite. After all this general deductions, it was confirmed that the standard machine will be good for a specific operation, mostly when a high percentage of coarse particles is desired from a quantity of a ore, while the fabricated machine would be a better one when different sizes is highly desired for a particular crushing operation of the same ore. All these now gives the final difference between the standard machine and the fabricated one, which are, the standard machine is a suitable one when accuracy is needed in terms of sizes of crushed material of a particular ore, but with low crushing rate, while the fabricated machine has higher crushing rate with different sizes of the same ore.

Table 1: Sieve Analysis of First Trial Test with Granite

	RETAINED				PASSED	
Nominal Aperture (µm)	Weight (g)	Cummulative Weight (g)	Percent Weight	Percent Cummulative Weight	Cummulative Weight (g)	Percent Cummulative Weight
2360	891.00	891	46.84	46.84	1011	53.16
1700	302.00	1193	15.88	62.72	709	37.28
1180	94.00	1287	4.94	67.66	615	32.34
850	197.00	1484	10.36	78.02	418	21.98
455	141.00	1625	7.41	85.43	277	14.57
300	80.00	1705	4.21	89.64	197	10.36
250	76.00	1781	3.99	93.63	121	6.37
180	64.00	1845	3.37	97.00	57	3.00
150	30.00	1875	1.58	98.58	27	1.42
75	27.00	1902	1.42	100.00	0	0

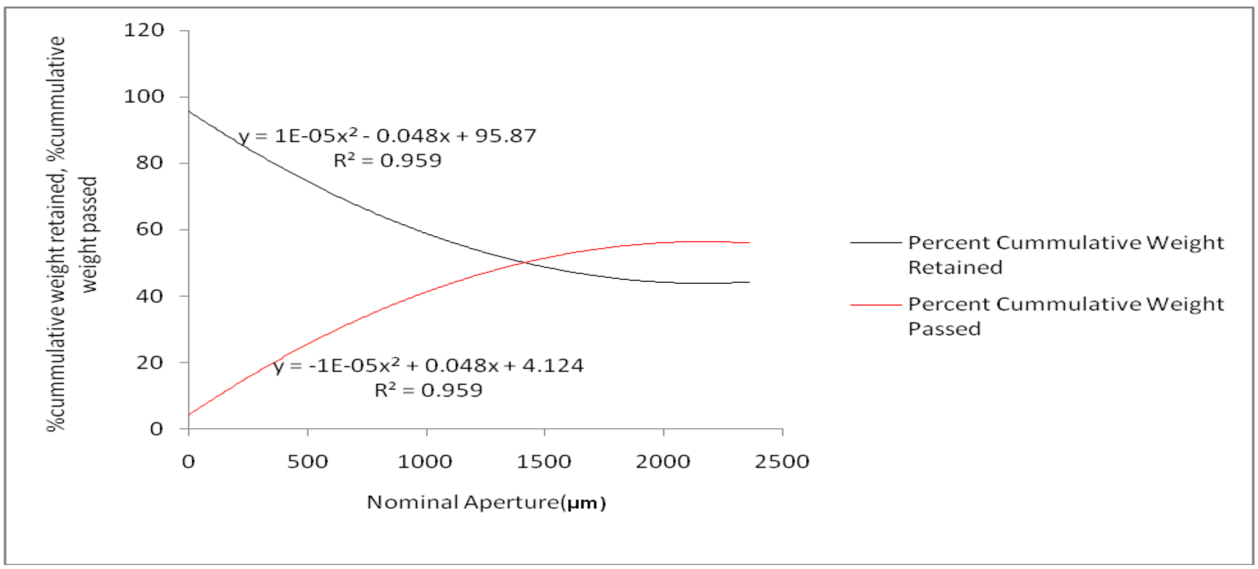

Figure 2: Sieve analysis graph of % cumulative weight retained and passed of Granite against the Nominal Aperture from the fabricated machine

Table 2: Sieve Analysis of First Trial Test with Dolomite

	RETAINED				PASSED	
Nominal Aperture (µm)	Weight (g)	Cummulative Weight (g)	Percent Weight	Percent Cummulative Weight	Cummulative Weight (g)	Percent Cummulative Weight
2360	632.00	632	32.25	32.25	1328	67.75
1700	634.00	866	11.94	44.19	1094	55.81
1180	299.00	1165	15.25	59.44	795	40.56
850	230.00	1395	11.74	71.18	565	28.82
455	214.00	1609	10.92	82.10	351	17.90
300	91.00	1700	4.64	86.74	260	13.26
250	84.00	1784	4.28	91.02	176	8.89
180	69.00	1853	3.52	94.54	107	5.46
150	47.00	1900	2.40	96.94	60	3.06
75	60.00	1960	3.06	100.00	0	0

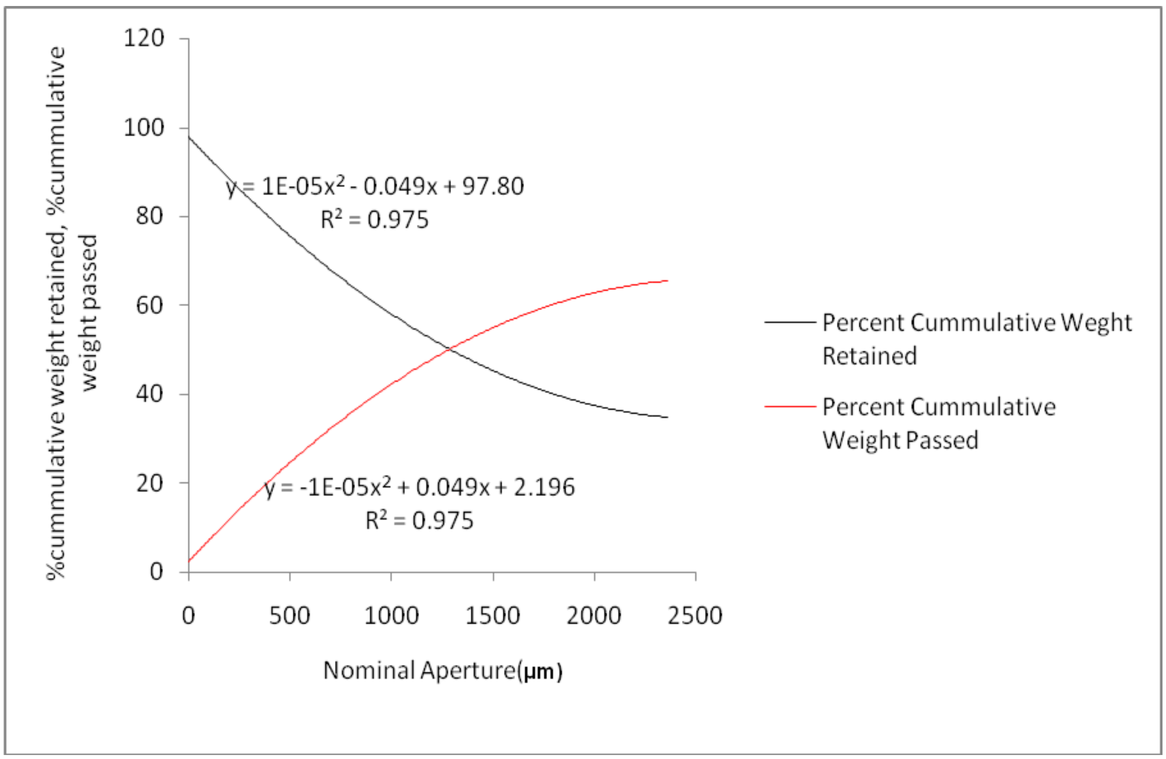

Figure 3: Sieve analysis graph of % cumulative weight retained and passed of Dolomite against the Nominal Aperture from the fabricated machine

Table 3: Sieve Analysis of Crushed Granite with Standard Machine

	RETAINED				PASSED	
Nominal Aperture (µm)	Weight (g)	Cummulative Weight (g)	Percent Weight	Percent Cummulative Weight	Cummulative Weight (g)	Percent Cummulative Weight
2360	1296.00	1296	64.90	64.90	701	35.10
1700	124.00	1420	6.21	71.10	577	28.89
1180	101.00	1521	5.06	76.17	476	23.83
850	82.00	1603	4.10	80.27	394	19.73
455	54.00	1657	2.70	82.97	340	17.03
300	93.00	1750	4.66	87.63	247	12.37
250	71.00	1821	3.56	91.19	176	8.81
180	53.00	1874	2.65	93.84	123	6.16
150	47.00	1921	2.35	96.19	76	3.81
75	76.00	1997	3.81	100.00	0	0

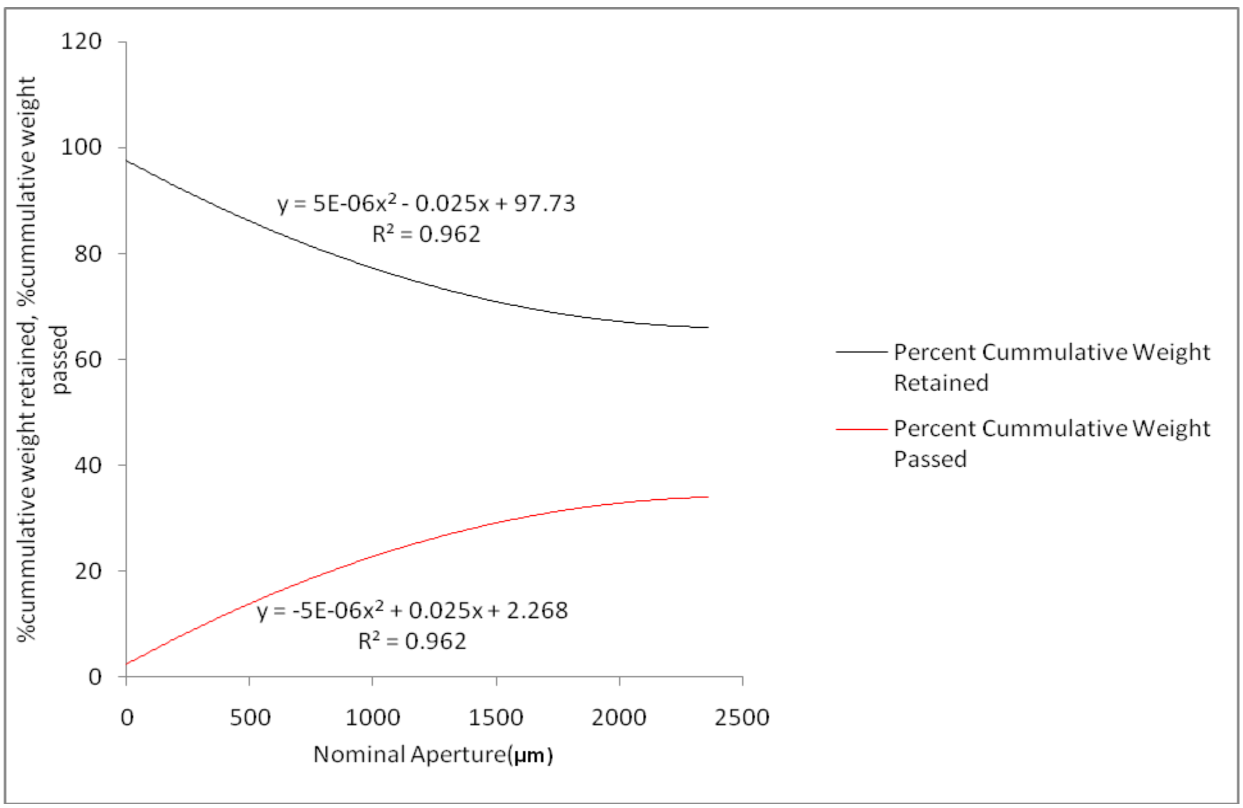

Figure 4: Sieve analysis graph of % cumulative weight retained and passed of Granite against the Nominal Aperture from the Standard machine

Table 4: Sieve Analysis of Crushed Dolomite with Standard Machine

	RETAINED				PASSED	
Nominal Aperture (µm)	Weight (g)	Cummulative Weight (g)	Percent Weight	Percent Cummulative Weight	Cummulative Weight (g)	Percent Cummulative Weight
2360	1250.00	1250	62.53	62.53	749	37.47
1700	96.00	1346	4.80	67.33	653	32.67
1180	58.00	1404	2.90	70.23	595	29.77
850	34.00	1438	1.70	71.93	561	28.07
455	77.00	1515	3.86	75.59	484	24.21
300	107.00	1622	5.35	81.14	377	18.86
250	134.00	1756	6.70	87.84	243	12.16
180	93.00	1849	4.65	92.49	150	7.51
150	61.00	1910	3.05	95.54	89	4.46
75	89.00	1999	4.46	100.00	0	0

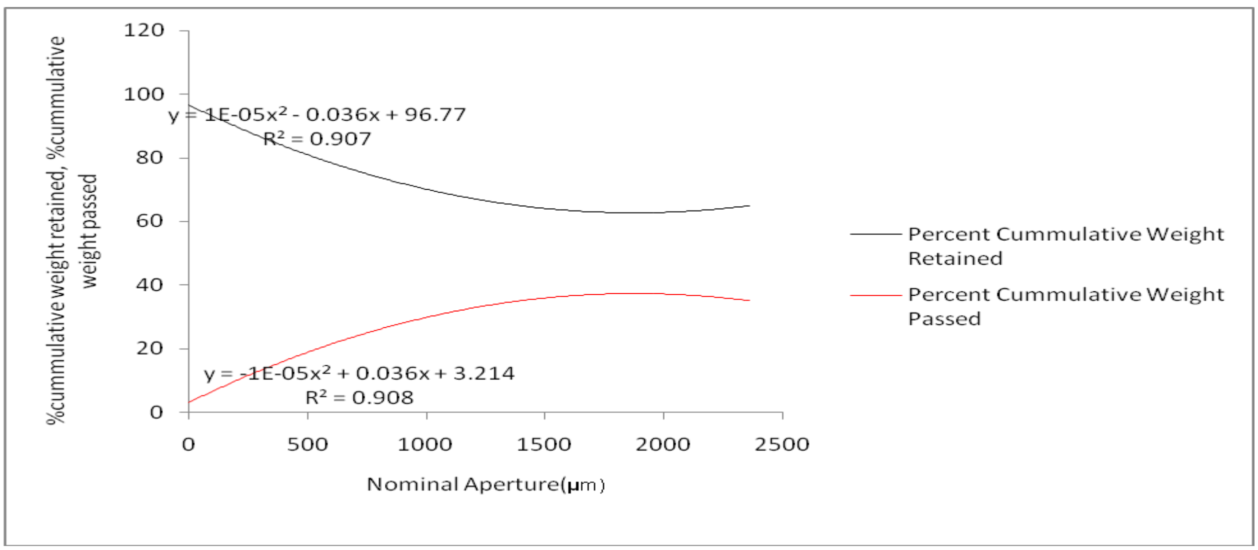

Figure 5: Sieve analysis graph of % cumulative weight retained and passed of Dolomite against the Nominal Aperture from the Standard machine

CONCLUSION

A laboratory size and easy to maintain hammer mill machine which could be well adopted by research institutions with local materials was designed and fabricated. The machine was subjected to test using two available minerals such as dolomite and granite with masses 2kg, 4kg and 6kg for each mineral. The output of the machine was satisfactory. Also, the sieve analysis to ascertain the crushability and predict the energy consumption rate of the machine was satisfactory. Sequel to this fact, the machine appears to be capable of crushing other minerals such as limestone and talc with a meaningful crushing capacity and reasonable energy consumption.

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Figure 6: Showing the aerial view of the Hammer mill