Effect of Fragmentation on Loading at Obajana Cement Company Plc, Nigeria

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Abstract – Evaluation of fragmentation distribution is necessary for the assessment of the effectiveness of the blasting operation against the standard handling capacities of loading, hauling and primary crushing equipment. Investigation was carried out on this by varying these variables and mathematically estimating their outcomes using the Kuz-Ram model. Likewise, the image analysis was adopted during the blast operations using the SPLIT Desktop software. The mean sizes of each were plotted against the excavator's digging time. The result indicated that time lag in loading the different fragment sizes had an average of 2 seconds increase for every 10cm increase in the mean fragment size. The Kuz-Ram model – a prediction model, although having the same positive trend as the actual result, was found to overestimate the mean fragment size as compared to split desktop software.

Key words: Fragmentation, Loading, Image analysis, Kuz-Ram and Split Desktop Software

1.0 INTRODUCTION

Evaluation of fragmentation is critical to the efficiency of mining operations such as digging and loading rates, haulage and crushing. Therefore, it is necessary to relate the outcome of the blast operation to the handling capacities of the mine fleet handling the loading and hauling processes in order to achieve the highest possible productivity

In fact, rock fragmentation is a wide phenomenon involving so many parameters responsible for controlling its outcome. This has made it a field with so many problems and undecided questions even with its great impact on all other mine processes and the productivity of the entire mining operation. The key objective of production blasting is to achieve optimum rock fragmentation. The degree of fragmentation plays an important role to minimize the overall production cost including loading, hauling, and crushing cost [1]. [2] Studied a new model for prediction of rock fragmentation by blasting which was based upon the basic concepts of rock engineering systems (RES). They concluded that RES based model predictor with higher R2 and less root mean square errors (RMSE) perform better than the other models.

Rock fragmentation refers to a process of size reduction of large rock masses into sizes suitable for the workings of subsequent equipment and machineries. This is often obtained by the process of drilling and blasting. [3] stated that when rock is blasted, the resulting fragmentation size distribution produced has a significant effect on all further downstream processes, especially loader and truck productivity in the loading and hauling phases of the mining operation.

[4] says that blast fragmentation has two major effects on loading and haulage performance in mining operation via Diggability (digging time) and Bucket payload (void ratio and fill factor).

"If rock fragmentation is not controlled, it can increase production cost and delay the quarrying process due to unnecessary secondary blasting or crushing. Therefore, blasting design should take into account the findings of rock fragmentation assessment to cut down the mining cost and shorten the work time" [5]. He further stated that blast result affects the productivity of the loading equipment, not only because of the size distribution of the material, but also because of its swelling and geometric profile of the muckpile.

Significant research has been carried out over the years into what effect blast designs and techniques have on the final product in the mining process. There are numerous parameters that can be altered to deliver downstream benefits – one of which is fragmentation; the key is to determine which changes are appropriate for the rock body in question. The effect of fragment size on loader and hauler productivity might have not received adequate attention but there exist considerable correlation between the fragment size and the productivity of loading and hauling operations.

The mechanism of fragmentation is difficult to describe as there are so many contributing factors to its result, this include parameters as; the spacing and burden distances, the drilled hole diameter, specific charge, type of explosive, effect of delay timing, the blast pattern and rock heterogeneity [6]. All these are the precursor of a blasting operation which must be efficiently tailored and correlated to obtain what will be defined as optimum fragmentation.

Knowledge of the fragmentation mechanisms in explosive loaded rock is critical for developing successful methods for excavating rocks rapidly for a variety of purposes, and has advanced considerably in the last twenty years [7]. This has tremendously helped in the improvement of excavation, loading, hauling and crushing operations- all of which are greatly impacted by fragment size distribution. This also contributes to significant efficiency, cost and energy savings for downstream processing operations.

[8] Discovered that no correlation exists between fragment size and loading rate until a boulder was encountered. The presence of boulders greatly increased the loading time. [9] Conducted loader productivity studies in limestone and sandstone mines. The time study of loader cycle time was compared with the fragmentation of the muck pile in two different rock. It was concluded that the cycle time is directly related to the fragment size.

[10] Investigated the effect of powder factor on dragline productivity, it was noted that increasing the powder factor enhances fragmentation and hence dragline productivity, but it was observed that increasing powder factor beyond an optimum region results greatly in reduction of bucket

fill factor. [11] Presented a case study to quantify the effect of fragmentation on mine productivity. This study focused mainly on hauling operations. It was concluded that smaller fragmentation increased mine productivity by increased tonnage of individual dipper and hauler cycle.

[6] Studied the effect of fragmentation on loader efficiency and focused specifically on the size distribution of blasted materials and quantifying its effect on loader productivity. Consequently, they concluded that the mass of the muck in the bucket decreases with increase in the particle size of the muck and the force required to penetrate into the muck is less, the bucket collects greater amount of material

[12] Studied the effect of blasted rock particle size on excavation machine loading performance. The research project originally consisted of performing mine site visits and collecting video camera images from typical front-end loader, cable shovel, and hydraulic shovel applications. The results suggested that there was little to be gained by attempting to match the performance of loading machines (loading cycle time and maximum production) with only size features of excavated materials. [13] conducted model studies of loading equipment as a function of rock fragmentation and observed fairly good linear correlation between 50%, 80% and 90% passing size and bucket fill factor.

[14] Studied shovel digging time to obtain data on the effects of explosive energy consumption on shovel productivity. It was observed that explosive energy is not the only factor affecting fragmentation but rock mass structure with respect to the blast direction also has influence.

The SPLIT is image analysis software developed by the University of Arizona to figure out size distribution of rock fragment [15]. Photo analysis or Digital Image Analysis Technology (DIAT) in mining operations can provide an automated system that forewarns a company of potential problems with materials, leading to economies and reduced damage caused from over-sized materials. It can also help determine the effectiveness of blasts [16].

Consequently, this research aims at analyzing fragment size and their effect on loading so as to determine optimum fragmentation for effective equipment utilization.

2.0 METHODOLOGY

2.1 Data Collection

Based upon the blasting operations carried out at Obajana Cement Company, a database was prepared as indicated in Table 1. In this database, burden (B), spacing(S), diameter of hole (D), bench height (H), blast pattern factor (P), stemming length (L), length of bottom charge (Lb), length of column or top charge (Lt), powder factor(K), relative effective energy of explosive(REE), mass of explosive per hole and standard deviation of drilling error were measured or calculated as in put parameters to the model. The digging time of each muck was taken to get a much more precise effect of the size distribution on the loading process. A total of 10 observations were made for all mucks.

A digital camera was used to get the image of the blasted material in the bench face which was used in SPLIT desktop software. Image samples were obtained after blasting operation. Approximately five to seven (5-7) pictures were taken at each blasting; and three to five (3-5) pictures were used for SPLIT desktop software as shown in Plates A-F. A plastic ball of 160mm diameter was used as the scaling object for the size distribution analysis. The same scale material was used from image to image analysis of all pictures in SPLIT regarding each blasting and later delineated. The digging time for each muckpile was also recorded.

2.2 Determination of Fragmentation Distribution

Kuz- Ram modelis a rock fragmentation prediction model developed by [17], and was first presented at the Lulea conference in 1983. It has since witnessed various modifications and development as given in Equation (1) below.

$$X_{50} = A * \frac{Q^{1/6}}{K^{0.8}} * \left(\frac{115}{REE}\right)^{0.633} \quad ...(1)$$

Where, X_{50} = Mean size (cm) – 50% passing, A = Rock Factor , K = Technical Powder Factor (excluding sub drill) (kg/m^3) , Q = Mass of explosive in blast hole (excluding sub drill) (kg) and REE = Relative Effective Energy of explosive

The formulae for calculating the percentage passing is given in Equation (2)

$$\%\text{passing} = 100 - \left(e^{-0.693} * \left(\frac{meshsize}{X_{50}}\right)^n\right) ...(2)$$

The uniformity index n is derived from an Equation developed by [18] as presented in Equation (3) below.

$$n = \left[2.2 - 14\left(\frac{B}{D}\right)\right]\left[0.5\left(1 + \frac{S}{B}\right)\right]^{0.5}\left[1 - \frac{Z}{B}\right]\left[0.1 + \frac{abs(L_b - L_t)}{L}\right]^{0.1}\left[\frac{L}{H}\right]P ...(3)$$

Where: n is uniformity index, B is burden (m), D is the hole diameter (mm) , S is spacing (m) , Z is standard deviation of drilling error (m), L_b is bottom charge length (m) , L_t is top charge length (m), H is bench height (m) and P is the blast pattern factor (P = 1.0 for square pattern and 1.1 for staggered pattern)

3.0 RESULTS AND DISCUSSIONS

It is normally desirable to have uniform fragmentation (values of 1 or greater), thereby avoiding both excessive fines and oversize fragments in the broken ground [19]. In other to improve the uniformity index, so we have a value of at least 1.5, a model was developed on the Microsoft excel platform to calculate the uniformity index. It incorporates the parameters involved in the Cunningham formula as stated in Equation (3), allowing the optimization of some parameters such as burden and spacing while keeping the others constant so as to compare the results of the variables been modified.

The design of the blast is a pointer to the result of the blast, and the parameters embedded in the blast pattern. From the results in Table 2, it indicates an index of 1.6 as the highest value and would have been the best for this assessment, since it would yield the most uniform fragmentation distribution, but the burden and spacing value which generates this uniformity index value contradicts a rule which says the burden should not be less than half the spacing as it results into rough saw-toothed face. Therefore it is desirable to choose one within the confines of this rule.

For the staggered pattern the values 2.5m and 6m can be taken as appropriate since row and hole delays are employed in the blast design, this give us a uniformity index of approximately 1.5. This is an acceptable value because when tested using the Kuznetsov's Equation, it generated a prediction of 105.57cm. The primary crusher installed at the mines has a gape of 1.5m and has no problem handling materials of an average of 1m. The above result signifies an improvement from the earlier value of 113.98*cm,* which will lead to improvement in the loading process and thereby improve the production efficiency.

A uniformity index of 1 and above is preferable as it results in a more uniform fragmentation distribution with fewer fines and less boulders. In Equation (3), it shows that the uniformity index is approximately 1.4 and using Equations (1) and (2), the results of the mean size and % passing are 114cm and 26.85% respectively. The benchmark information will now be used to generate a prediction of what the result of the blasting operation should be and compare it with the associated photographs. For each variation in the spacing and burden values, there is a corresponding change in the powder factor, thereby leading to a change in the mean fragment size as described below, Table 2 shows the results of these variations on the powder factor and mean size values.

$$\text{Powder factor (k)} = \frac{mass\ of\ explosive}{volume\ of\ rock\ blasted} \ldots (4)$$

Table 1: Blast design database for the Quarry

Benchmark	Values
Burden (B)	3m

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Spacing (S)	5.5m
Diameter of hole (D)	0.127m
Bench height (H)	10.5m
Blast pattern factor (P)	1.1
Stemming length(L)	3m
Length of bottom charge (L_b)	2m
Length of column or top charge (L_t)	5.5m
Powder factor (Kg/m^3)	0.638
Relative effective energy of explosive(REE)	1.5
Mass of explosive per hole (Kg)	110.4
Standard deviation of drilling error(W)	0.3m

Table 2: New Powder factors and Mean sizes resulting from Burden and Spacing variations

Spacing	Burden	Powder Factor	Uniformity index	Mean Size (X_{50})
4.0	3.0	0.876	1.249	88.33
4.5	3.0	0.778	1.292	97.13
4.5	4.0	0.584	1.177	122.18
5.0	3.5	0.601	1.272	119.41
5.0	3.0	0.701	1.335	105.57
5.5	3.0	0.637	1.376	113.98
5.5	2.0	0.956	1.509	82.37
5.5	2.2	0.869	1.485	88.90
5.5	2.5	0.765	1.445	98.45
5.5	2.8	0.683	1.404	107.80
5.5	3.2	0.597	1.348	120.05
6.0	3.0	0.584	1.416	122.18
6.0	2.5	0.701	1.490	105.57
6.5	3.0	0.540	1.455	130.08
6.5	2.0	0.809	1.606	94.14

Plate A

Plate B

Plate C

Plate C Plate D Plate E

Photographic images of muckpiles which were systematically taken at different time during the loading of the muckpile as indicated in Plates A-F, the digging time for each muckpile was also recorded against their mean fragment sizes after analysis it in split desktop. The mean size versus the average digging time is shown in Table 3.

Table 3 is the result of the mean sizes of the sample images and the corresponding mean digging cycle time. The digging cycle time is used instead of the loading cycle time so that variations in the other stages of the loading phase which has no association with fragment size distribution can be eliminated thereby ensuring a higher degree of accuracy in the result.

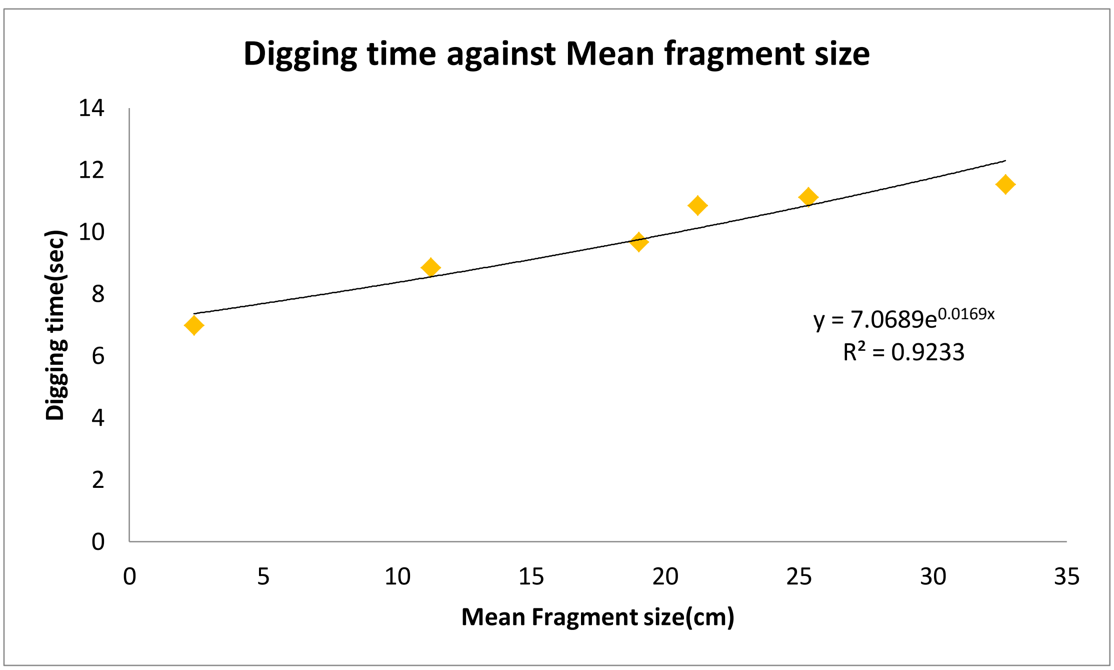

Figure 1: Digging Time against the Mean Fragment Size

The result of this Figure 1 shows a positive relationship albeit not perfectly linear relationship between the digging time and the mean fragment size. This means that an increase in the fragment size leads to a corresponding increase in the digging time. It is reasonable to assume that increase in the fragment size might lead to an exponential increase in loading time given the imperfect but positive relationship that exists between these variables. The difference might be assumed as small but it shouldn't be regarded as insignificant. A difference of 10cm in the mean fragment size as depicted by the recorded data can lead to a savings of about 2secs on each pass of the Excavator. This is considered good, as it will culminate into significant time and consequently cost savings in the loading process.

Table 3: Mean Size versus Digging Cycle Time

Plates	Mean Fragment size (cm)	Mean digging cycle time (sec)
A	21.23	10.85
B	11.25	8.85
C	25.35	11.11
D	32.71	11.52
E	19.02	9.67
F	2.41	6.99

Sequel to the instructions on the procedure for analysis of Digital image for fragmentation distribution, a total of six images were analyzed, Figure 2 is the output of the combined granulometry analysis with the SPLIT software essentially consists of a cumulative size graph and table.

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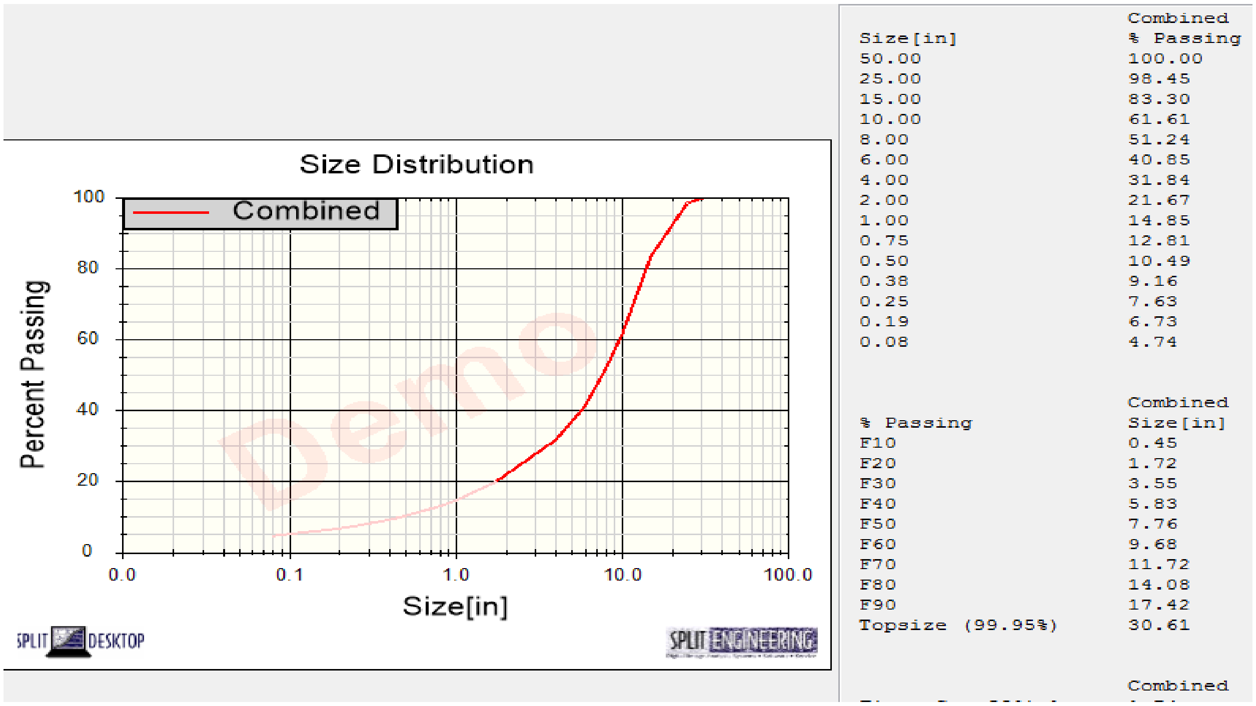

Figure 2: A combined result of the all the plates

IMAGING ANALYSIS AND KUZ- RAM COMPARISON

From the results of the analysis using SPLIT, the highest mean size is 12.4 inches which is approximately 32.7cm while the lowest is 0.95inches, approximately 2.4cm. The mean fragment size for the combined result is given as 7.76 inches which is approximately 19.7cm as shown in Table 4

Table 4: Deviation from KUZ-RAM Model

Parameters	**Mean Size**	**% passing at 63.5cm**
Kuz-Ram	114cm	98.45
Imaging Analysis	19.7cm	26.85

The values above show a significant deviation from the prediction made by the KUZ-RAM model. This is a deficiency in the model in that it over estimates the predicted value through under estimation of the fines produced by the blasting operation.

The Kuz-Ram model as a prediction tool has been seen to only be able to generate a trend of the expected fragmentation behavior, and does not quantitatively depict the result as it is lacking in many other parameters which influence fragmentation, such as: rock properties and structure (variation, relationship to drilling pattern, dominance of jointing); blast dimensions (number of holes per row and number of rows); bench dimensions (bench height versus stemming and subdrilling); timing between holes, and precision of the timing; detonation behaviour, in particular detonation velocity (VoD; decking with air, water and stemming; and edge effects from the six borders of the blast, each conditioned by previous blasting or geological influences [20].

CONCLUSION

Fragmentation definitely has an effect on the loading and hauling system efficiency. Although it is often neglected, thereby leading to the need for either excessive secondary blasting or breakage and excessive fines. This study has shown that inefficiencies in blasting should not be overlooked as it is the precursor to the resulting fragmentation distribution. In fact the parameters that control the result of fragmentation are those contained in the blast design.

This study has revealed the positive relationship that exists between digging rate, payload and fragment size, and also analyzed the result of the blasting process at Obajana Cement Company, with suggestions or prediction on how to better the process. This was done through manipulation of some of the blasting parameters, basically the spacing and burden and consequently the powder factor, the newly suggested burden and spacing values will reduce the mean fragment size by 10cm and consequently save an average 2sec on each pass of the excavator.

5.2 RECOMMENDATIONS

The following are the recommendations hereby made, both for application at the site of study and for further studies:

1. The cost implication of the effect of varying fragment sizes should be determined in other to know how much goes into processes as secondary breakage/blasting, equipment wear etc. this would require a long-term process of producing different fragmentation sizes and monitoring the effect of this on the equipment costs, particularly the engineering component of this cost and the tyre components in haulage equipment.

2. This cost can then be compared against the increased drilling and associated explosive cost for each modification of the fragment size, in other to determine which outweighs the other and be able to make a quantitatively informed decision.

3. Results of this research should be adapted in other to harmonize the fragmentation distribution, and reduce the time spent on side casting of boulders.

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