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Evaluation of Rock and Explosive Properties for Fragmentation Characterization: An Application of WipFrag

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ABSTRACT: *This study investigates the rock explosive properties in selected Lokoja quarries, Nigeria, with the goal of characterizing fragmentation for optimized downstream operations. The analysis includes porosity, UCS values, and permeability assessment in Gitto quarry, highlighting advantages in material application. Comparisons between rock formations (Q1 and Q2) reveal varying compressive strengths, crucial for determining appropriate explosive energy for efficient fragmentation. Blast design parameters from Q1 and Q2 indicate consistent values, aiding in operational planning. Fragmentation analysis, conducted using WipFrag software, delineates size ranges and classifies the blast as having a moderate distribution. Correlations between blast fragmentation size and powder factor underscore the impact on efficiency. A classification chart and table are presented for convenient interpretation of results, providing valuable insights for enhancing blasting practices in Lokoja quarries and ultimately improving productivity. The fragmentation analysis result carried out in this study using WipFrag software shows that the 50%, 80% and Maximum block size passing size ranges from 539.94 – 1349.53 mm, 690.07 – 1907.81 mm, 808-2280 mm respectively. The blast fragmentation sizes are classified as moderate distribution blast based on the uniformity index value ranging from 1.95 to 2.4. The relationship between blast fragmentation size and powder factor was evaluated using linear correlation coefficient. It was noted that, X20, X50, X80 has high R^2 values greater than 60% respectively.*

KEYWORDS: rock, blasting, explosive, fragmentation, WipFrag, fragment classification

INTRODUCTION

The evaluation of rock and explosive properties for fragmentation characterization is crucial in optimizing mining operations. Rock mass attributes, blast design parameters, explosive properties are three groups of elements that have an impact on blasting operations [1]. The variables that can be controlled in blast design include burden, drill hole spacing, stem height, drill hole inclination, diameter, length, drilling pattern, blasting direction, sub drilling, blasting sequence [2, 3]. Taiwo and Adebayo mentioned that the criteria of explosive materials include the explosive type, density, strength, moisture heat resistance, specific charge, all of which can be altered [4]. The characteristics pertaining to the makeup of the rock mass make up the third group. These uncontrollable characteristics are among the factors that have the most impact on the outcomes of blasting [5, 6].

Several authors' work has mention that good blast fragmentation in mining operations provides several advantages. [7] explained that efficient blasting enhances ore recovery, reduces energy consumption during crushing and grinding, improves overall processing efficiency, and minimizes downstream processing costs. [8] and [9] also explained that optimal fragmentation also facilitates better ore handling, transportation, and ultimately results in increased productivity and profitability for mining operations.

More over when identical blast geometry and explosive energy input are applied to two different rock masses, they will result in very varied levels of fragmentation [10]. Literature explained that due to the fact that each rock mass has a unique propensity to resist being broken up by blasting, a property known as blastability [11, 12].

Rock fragmentation using Explosive energy has been thoroughly investigated through tests other techniques. Numerous downstream mining operations, such as loading, transportation, crushing, grinding, are impacted by the particles that are produced. The ideal rock fragmentation size is between 100 and 800 mm, which means the rock pieces do not require postblast treatment [13]. Majorly the efficiency of blast fragmentation is classified based on size distribution. The lack of a comprehensive understanding and systematic assessment using tools like WipFrag hinders efficient blasting practices. This study aims to address this gap, focusing on the application of WipFrag for improved fragmentation analysis and subsequent mining performance enhancements. The effect of blast design on blast fragment characteristics is a critical aspect of mining operations. Inadequate blast design can result in suboptimal fragmentation, affecting downstream processes such as crushing and grinding [8, 14-15].

Seven to twenty-five percent of the explosive energy is used in fragmentation flinging [16]. The remainder of the energy is lost as fly rock, ground vibration, air blast, noise and backbreak, therefore, by lowering the amount of lost energy, blasting performance can be enhanced. The causes of fragmentation, such as rock-mass characteristics, blast geometry, explosive properties, have been researched by [17]. The strength discontinuity characteristics, density, porosity, the capacity of rocks to propagate shock waves are a few of the rock-mass properties that have been examined [18].

The effect of explosive properties on blasting outcomes is a pivotal factor in mining operations. Variables such as explosive type, energy, and initiation sequence significantly influence blast fragmentation, muckpile shape, and overall efficiency. This study also carried out a comprehensively analyze how diverse explosive properties impact blasting performance, seeking insights for improved blast design and downstream operational enhancements. The last section investigated the correlation between blast design parameters and resulting fragment characteristics, seeking insights for optimizing blasting practices and enhancing overall mining efficiency.

LITERATURE REVIEW ON BLAST FRAGMENTATION AND INFLUENTIAL FACTORS

Review of Rock Fragmentation

Rock fragmentation refers to the process of breaking a larger solid material, such as rocks or ores, into smaller pieces or fragments [19]. The degree of blast fragmentation significantly influences the overall productivity and economics of these industries. Rock fragmentation is a crucial aspect of mining and quarrying, influencing various downstream processes and overall operational efficiency [20, 21]. Efficient fragmentation ensures optimal ore recovery and processing, reducing energy consumption and operational costs. Numerous factors contribute to rock fragmentation, including geology, drilling practices, and blast design. Advances in technologies like laser profiling and image analysis have enabled more accurate measurement and analysis of rock fragment sizes, shapes, and distribution. Understanding fragmentation dynamics facilitates improved blast design, allowing for customization based on geological variations [22]. Furthermore, precise fragmentation analysis aids in equipment selection, reducing wear and tear on crushers and mills. This review highlights the multifaceted nature of rock fragmentation, emphasizing its pivotal role in enhancing the sustainability and profitability of mining and quarrying operations.

Geomechanical properties influencing fragmentation

Geochemical properties of rocks can also significantly influence fragmentation during blasting and drilling operations in quarrying and mining [23]. These properties encompass the chemical composition and mineralogy of the rocks, which can impact their response to explosive forces. One critical geochemical property is the mineral composition of the rock. Different minerals have varying degrees of hardness and brittleness, which can lead to variations in how the rock fractures and fragments during blasting [24]. The presence of certain chemical elements or compounds within the rock can also influence fragmentation behavior. For instance, the occurrence of reactive minerals, such as sulfides, can lead to the generation of gases during blasting, contributing to further fragmentation [25].

Techniques for measuring fragmentation

Measuring fragmentation is a critical aspect of evaluating the efficiency of blasting operations in quarrying and mining. Several techniques have been developed to assess the size distribution and characteristics of fragmented material including WipFrag software [26]. One common method is sieving analysis, where the crushed or blasted rock is passed through a series of screens with different mesh sizes, and the percentage of material passing through each sieve is determined, providing information on particle size distribution [27]. Image analysis involves capturing high-resolution images of the fragmented material and using specialized software to analyze particle sizes and shapes, providing detailed information on individual particles and size distribution parameters [28].

Advanced technologies such as laser scanning and photogrammetry offer 3D point cloud models of the blasted rock or muckpile, enabling accurate calculation of volume and size distribution of fragmented material [29]. Computer-based simulation techniques, like Discrete Element Method (DEM) simulations, can model rock breakage and fragmentation under blasting conditions, providing insights into fracture patterns and particle sizes generated during blasting [30].

WipFrag is a software tool widely used for blast image analysis in mining and quarrying. Employing advanced image processing algorithms, WipFrag accurately analyzes images of blasted material, providing valuable data on particle sizes, shapes, and distribution [31]. This information is crucial for optimizing blast designs and improving fragmentation outcomes. By automating the analysis process, WipFrag enhances efficiency and reduces human error, allowing for rapid assessment of blast performance. Its user-friendly interface facilitates quick interpretation of results, enabling mining professionals to make informed decisions for better blast optimization, ultimately contributing to increased productivity and cost-effectiveness in the extraction and processing of materials. The WipFrag software was adopted in this study for blast image fragmentation.

Case Study and Data Description

Description of case study area

Between latitudes 7°45'N and 7°53'N and longitudes 6°39'E and 6°48'E is Lokoja, which is where the rivers Niger and Benue converge (Figure 1-4). The complex of the basement lies beneath it. The town is strategically positioned and easily reachable because to Nigeria's excellent road system, which connects the country's north and south as well as its north and west. With a few isolated laterite-capped hills that range in elevation from 30 m to 400 m above sea level, the area has low to moderate relief. The Niger-Benue river system drains it. A dendritic pattern can be seen in the drainage system. The rainy and dry seasons, which are unique in Lokoja, each have their own characteristics. The dry season runs from November to March, whereas the rainy season runs from April through October. The average annual precipitation is between 1000 and 1500 mm, while the average annual humidity is at 70%. With 6.7 hours of sunshine on average every day, the yearly average temperature is 27°C. In the area, temperatures can reach as high as 33°C or 36°C. The region's vegetation is of the Guinea Savannah variety, with gallery forests that are denser lining parts of the rivers (Federal Ministry of Aviation, 2007). The location of the two quarries are shown in the Figures 1-4.

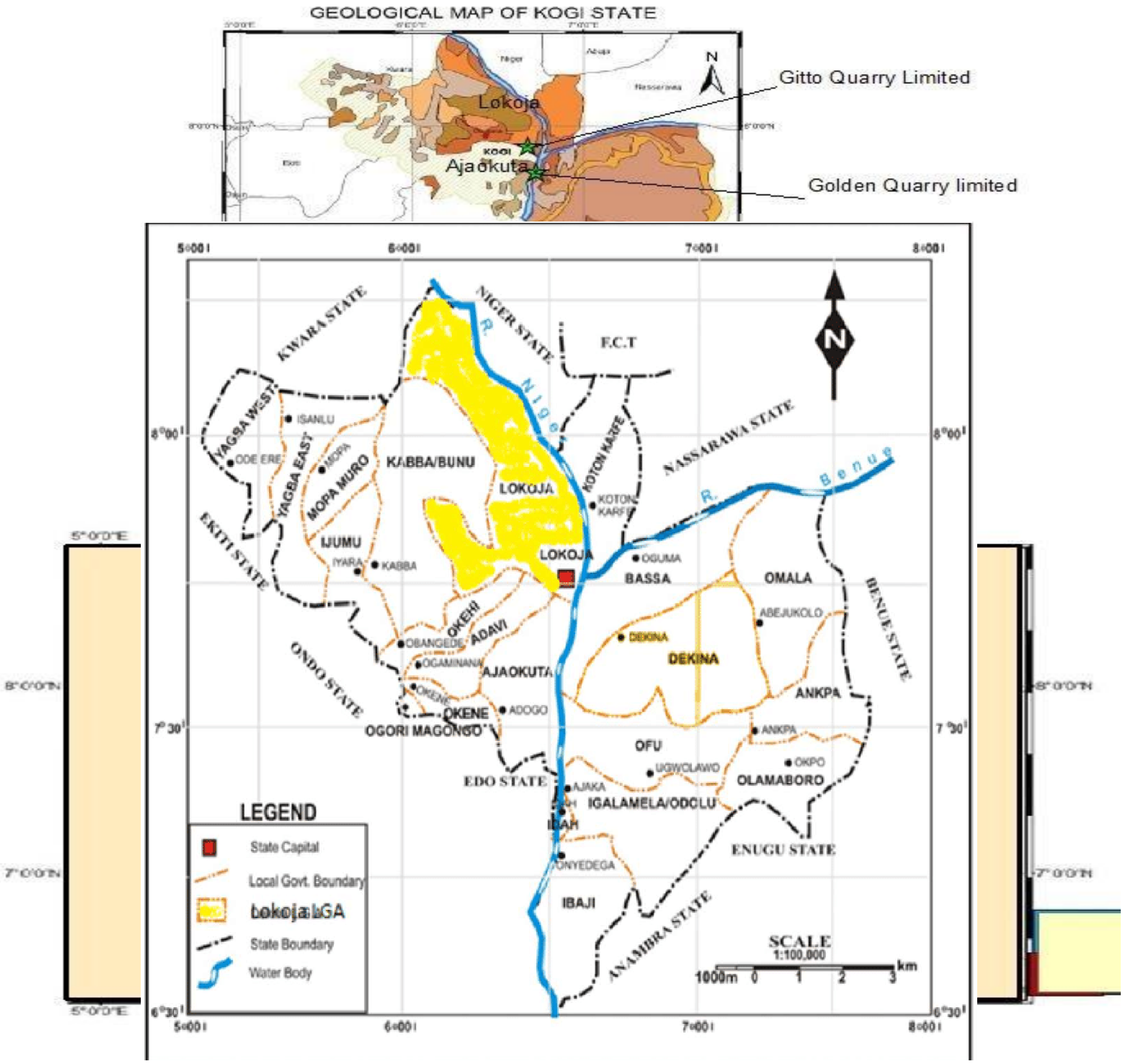

Figure 1: Geology Map of Kogi State showing Lokoja L.G.A

Figure 3.2 Geological Map of the Study Areas

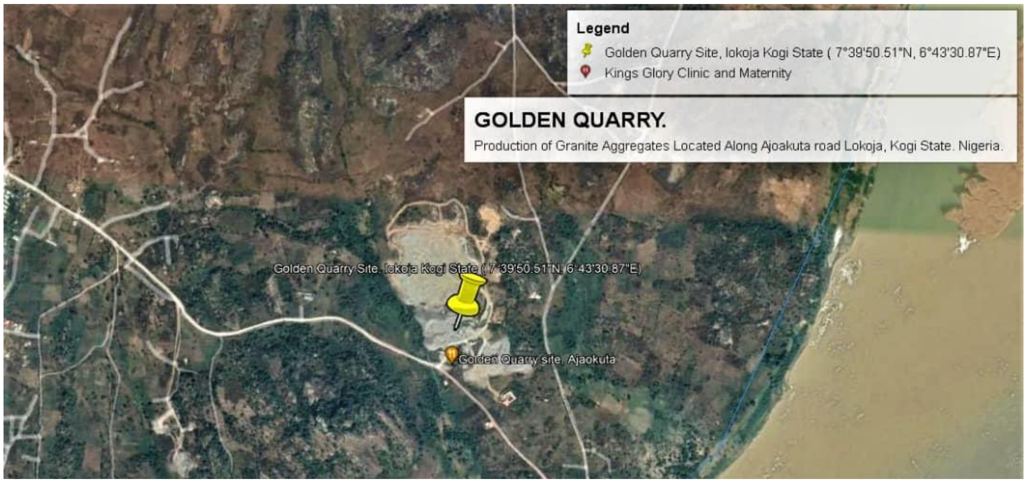

Figure 2: Map Showing the Location of Golden Quarry

Figure 2: Map Showing the Location of Gitto Quarry Limited

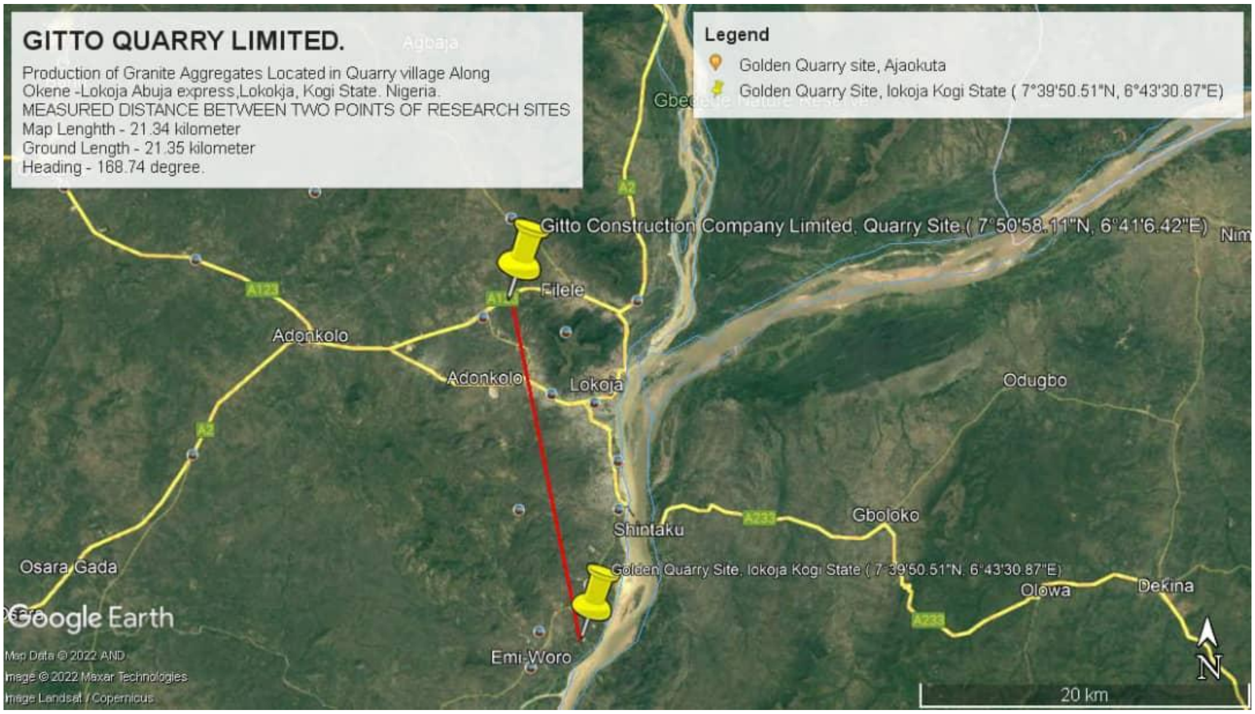

Figure 4: Map Showing the Relative Location and Distance of the Selected Quarries.

Sample Collection and Analysis

In this study, systematic sampling plan to collect rock samples was developed. Random locations were selected within each quarry to ensure representative sampling, each rock sample was labelled with essential information, including the quarry location, depth, date of collection, and geological description.

Determination of Rock Properties

Blasting parameters for each rock blast were obtained from the site. The needed parameters which include Number of blast holes, Average depth of blast holes, Diameter, Holes Spacing and Burden, Types and quantity of explosives was used. The followings were also determined from the measured parameters: Volume of rock blasted, Tonnage of rock blasted, Tonnage of Explosives used, Ratio of Tonnage of rock blasted to Tonnage of Explosives used.

Determination of Explosive Properties

The explosive properties of the case study mine were collected and documented. The explosive type, strength and density among other properties were collected for this study.

Determination of Rock permeability

Samples collected were subjected to several rock strength and physical lab tests. The permeability test was carried out on a cylindrical rock sample. The sample was placed in a permeameter, and fluid was injected at the center of the sample. The flow rate and pressure drop were measured, and permeability was calculated using Darcy's law, as expressed in Equation (1)

$$Q = -KA\frac{dh}{dl} \tag{1}$$

Where;
Q is the rate of water flow
K is the permeability
A is the cross sectional area
Dh/dl is the hydraulic gradient

Determination of Rock Hardness

The test involved the use of Schmidt impact hammer of type N for the hardness determination of lump rock samples. The rebound value of the Schmidt Hammer is used as an index value for the intact strength of rock material, but it was also used to give an indication of the compressive strength of rock material [32]. The standard method for the Schmidt hammer test as described by [32] was followed. The measured test values for the samples were arranged in descending order. The lower 50% of the values were discarded and the average obtained of the upper 50% values was used to obtain the Schmidt Rebound.

Determination of Rock Porosity

The porosity test was conducted on collected samples in according to ISRM [32]. The following equations were used to calculate the porosity, in Equation 2.

$$Porosty\ (ŋ) = \frac{Vv}{V} \times 100\% \tag{2}$$

Density

The dry density was determined according to ISRM [32]. Equation 3 was used to get the saturated volume of the sample.

$$\text{Saturated Volume of sample} = V_2 - V_1 \tag{3}$$

Where V_1 (ml) is the initial water level and V_2 (ml) is the final water level in the cylinder after the immersion of the irregular rock sample.
The dry density of the rock samples was calculated using shown in Equation 4

$$\text{Dry density of the rock sample} = \frac{M}{V_2 - V_1} \tag{4}$$

Where M (g) is the oven dried mass at a temperature of 105^0C.

Determination of Uniaxial Compressive Strength

Cylindrical core samples of diameter 50 mm and length 125 mm was prepared for compression under the compression machine in accordance with ISRM [32]. The load was subsequently applied continuously at a constant rate of 35 kN per minute. Failures occurred within 10 minutes of loading in all cases.
UCS of the rocks were calculated using Equation 5

$$UCS= \frac{P_{max}}{A} = \frac{P_{max}}{\pi\left(\frac{D}{2}\right)^2} \quad (5)$$

Where, P_{max} is load on specimen (N); A is the cross sectional area of sample (m^2); D is average specimen diameter (m); and UCS is expressed in MPa.

Blast Fragmentation Analysis Technique

Image analysis involves extracting meaningful information from visual data. The methodology typically includes pre-processing, where images are enhanced or normalized, followed by segmentation to identify regions of interest. Feature extraction captures relevant characteristics, and classification categorizes objects based on these features. Post-processing refines results and may involve filtering or merging. Machine learning techniques, such as deep learning, are commonly used for image analysis, training models on annotated data.

In this study, WipFrag software was used for the processing of blast images to analysis the fragmentation distribution sizes. Picture was taken, using digital camera, to get their images sizes and interpolated as below, for example: The blast design parameters data collected from blasts from two experimental sites were analyzed to find out their impacts on rock fragmentation level. The main important parameters which decide the fragmentation level of particular blasts are burden to hole diameter ratio, spacing to burden ratio, stemming column length, stiffness ratio, explosives amount and type, initiation mode and charge/powder factor. The image analysis approach used was in accordance to the description published by Taiwo et al. [9].
The flow sheet for the study methodology is present in Figure 5.

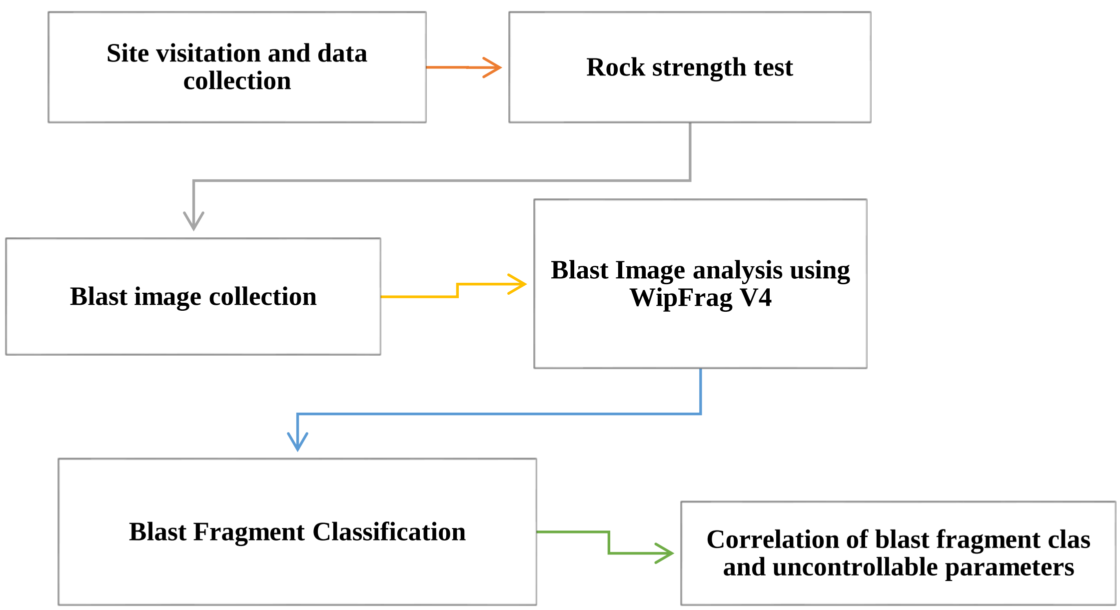

Figure 5: Flow Chart of the developed Classification model

RESULTS AND DISCUSSIONS

Rock Properties Result

Table 1 shows the result of the geotechnical properties of the rock samples collected from the chosen study area. The result shows that the rock formation in Gitto quarry has the highest water porosity and UCS value of 33% and 123 MPa respectively. The low permeability of both samples (1.2×10^{-17} m^2) might be significant in the context of quarrying. The Low permeability result as suggested by Cueto et al. [33] signifies that these rocks are less likely to absorb water, which may affect the fragmentation process. Water absorption can lead to changes in the mechanical properties of rocks and may impact the efficiency of explosive fragmentation.

Table 1: Rock properties Analysis Results

		Golden Quarry	Gitto Quarry
S/NO	PROPERTIES	Q1	Q2
1.	Permeability (m^2)	1.2×10^{-17}	1.2 x 10^{-17}
2.	Hardness	6 – 8	6 – 8
3.	Effective porosity/water absorption (%)	0.20	0.33
4.	Bulk Density (g/cm^3)	2.73	2.71
5.	Uniaxial Compressive Strength (MPa)	120	123

The moderate to high hardness (6-8) of both samples is crucial in assessing their resistance to abrasion during the blasting process. According to Ghorbani *et al.* [34], rock hardness affects the rock mechanics and excavatability. Mehrdanesh *et al*. [35] also noted that hard rocks require more energy for fragmentation, and the understanding of hardness is essential for selecting appropriate explosive strategies.

Focusing on the advantage of porosity, the lower effective porosity of Q1 (0.20%) may be advantageous in quarrying, as it implies less water absorption. This could lead to more predictable fragmentation patterns, as water-induced alterations in rock properties can affect the efficiency of explosives. Lower porosity can contribute to more controlled blasting outcomes.

The slight difference in bulk density between Q1 (2.73 g/cm^3) and Q2 (2.71 g/cm^3) may have implications for the selection and optimization of explosive charges. Bulk density affects the energy transmission and distribution during blasting, and understanding this property helps in designing effective blasting patterns.

The higher uniaxial compressive strength of Q2 (123 MPa) compared to Q1 (120 MPa) indicates that Q2 may be more resistant to crushing forces. This information is vital for determining the appropriate explosive energy required for efficient fragmentation. Rocks with higher compressive strength might need higher explosive energy for effective breakage.

In the context of this study, understanding these rock properties is crucial for evaluating and optimizing the blasting process in selected quarries in Lokoja. The information gathered from these property evaluations will guide the selection of suitable explosives and blasting techniques tailored to the specific rock characteristics in the quarries.

Blast Design and Explosive Properties

Blast Design Parameters

The average values of various blast parameters, such as hole diameter is 10 m hole depth with a 1 m sub drill and a 2 m stem height, indicate a detailed consideration of the geological layers in the quarries. These values suggest an intention to penetrate specific rock formations efficiently and optimize stemming for effective energy transfer during blasting.

The study shows that the chosen hole diameter of 6 inches indicates a balance between precision and efficiency. This diameter is suitable for a variety of rock types and provides a compromise between the need for effective fracturing and the practicalities of drilling operations.

The spacing and burden of 2.5 meters suggest a relatively tight drilling pattern. This may be indicative of a desire for controlled blasting to achieve a more uniform fragmentation. The values align with the intention to optimize fragmentation while considering the geological characteristics of the quarries in Lokoja. The choice of a staggered drill pattern and the number of holes (150) indicate a systematic approach to blasting. The staggered pattern suggests a deliberate effort to enhance fragmentation, while the number of holes is a key factor in achieving the desired tonnage, considering the rock's response to blasting.

The study revealed that Q1 and Q2 have average specified tonnage of 25,000 tons and the powder factor of 0.45 kg/m^3 which is crucial values for estimating the required explosive quantity. These values suggest an aim to achieve efficient fragmentation without excessive energy consumption, aligning with the project's goal of characterizing fragmentation in the quarries.
In summary, each parameter value has been selected with a specific purpose in mind, reflecting a careful consideration of the geological conditions in Lokoja and the project's objective to optimize fragmentation for efficient quarrying operations.

Explosive Properties Result

Dynogel stands out as an exceptionally powerful explosive employed in the selected quarry under study. Distinguished by its non-nitroglycerin composition and remarkable strength, this cap-sensitive explosive is available in watergel or packaged emulsion forms, suitable for blast holes of all diameters. Notably resistant to water, Dynogel significantly minimizes the emission of noxious fumes. With an excellent capacity for fragmentation, it enables substantial throw and facilitates the smooth movement of fractured rocks. The firm consistency of Dynogel ensures complete borehole coupling, ultimately optimizing blasting outcomes. Representing our most potent formulation, this explosive boasts high density and velocity, making it a standout choice for quarry operations. Table 2 presents the various properties of the explosive used.

Table 2: Properties of the explosive used at the Quarry

	Quarries	
	Q1	**Q2**
Detonation velocity	5250 m/sec	5250 m/sec
Density	1.19 g/cc	1.20g/cc
Sensitivity	No 6 detonator	No 6 detonator
Water Resistance	Excellent	Excellent
Powder Factor	0.35 kg/m^3	0.35-0.45 kg/m^3

Blast Fragment Size Analysis Results

Before blasting the rock on-site, all blast design and explosive characteristics were measured. With an appropriate camera, photos of the complete muck pile with the scaling object in place were recorded immediately after blasting. Images were imported using WipFrag version 4. Each image of a blast was outlined using both automatic and manual editing tools. After sifting the delimited images, the fragmentation distribution curve was derived. Figures 6 illustrates the WipFrag meshing images for selected blast outcomes utilized for determining the uniformity index. The fragmentation size distribution curve was utilized obtained with the mean size, 80% passing sizes, uniformity index (n), and maximum size for each blast result.

The analysis result shows that the 50%, 80% and Max size passing size ranges from 539.94 – 1349.53 mm, 690.07 – 1907.81 mm, 808-2280 mm respectively. The blast fragmentation sizes are classified as moderate distribution blast throw based on the uniformity index value ranging from 1.95 to 2.13. Figures 6 present the distribution curve and delineated image results from selected blast rounds. The software result shows that the blast fragmentation efficiency ranges from 40 to 56% which demand adjustment of the case study mine blast design to minimize the boulder production and optimize the explosive energy towards good fragmentation.

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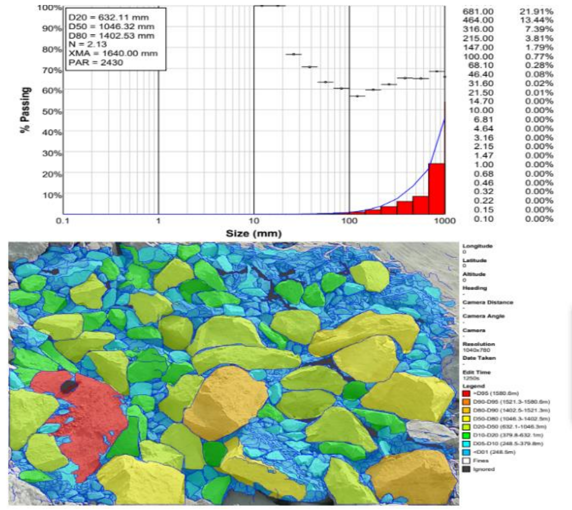
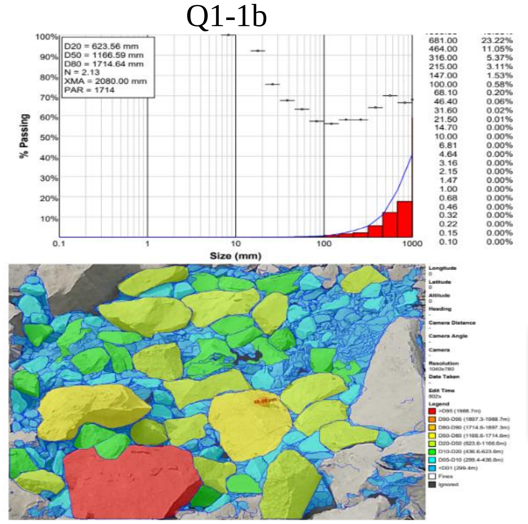
Q1-1a



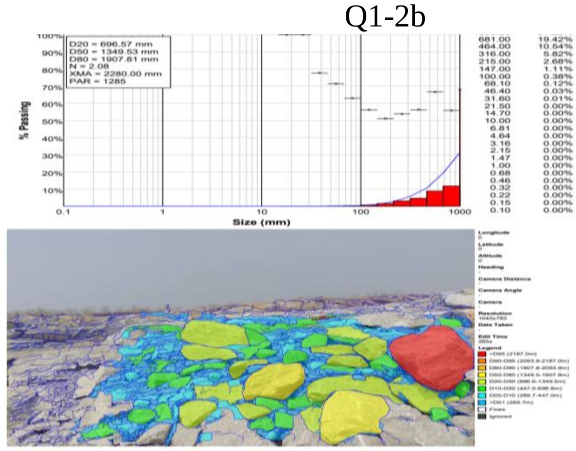
Q1-1b


Q1-2a

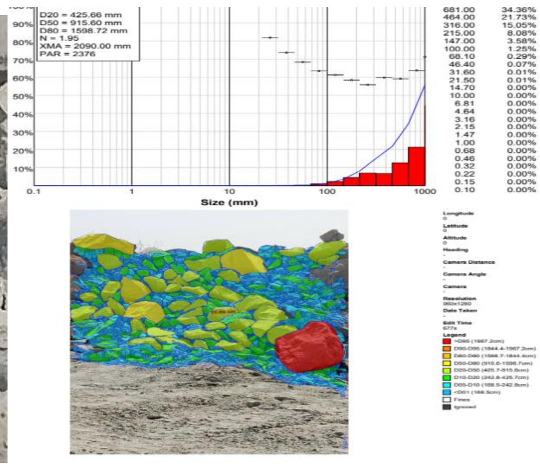


Q1-2b

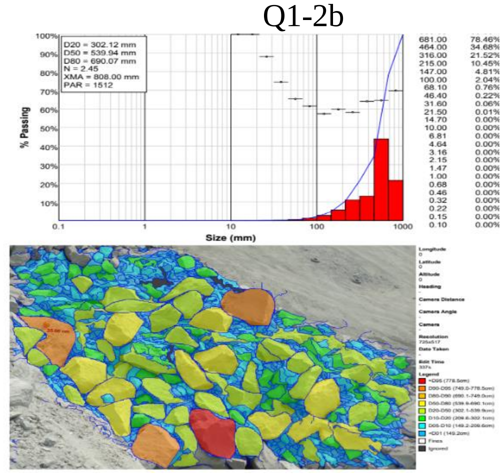

Q2-1a



Q2-1b



Q1-2a Q1-2b



Q2-2a Q2-2b

Figure 6: Fragmentation Analysis Result for selected Five blast rounds

Table 3 presents the 80%, 20%, 50%, and uniformity index of 15 blast rounds obtained from the case study mine. The fragmentation result was classified based on the uniformity index as explained by Nourian and Moomivand [36]. The classification shows that Q1-1, Q1-2, Q2-2-6, and Q1-5-6 are classified as well distributed fragmentation. The study revealed that, higher powder factor enhances good blast fragmentation uniformity as shown in Table 3.

Table 3: Blast Fragmentation size Distribution Classification

Blast	B	PF	X20	X50	X80	N	Fragment Classification
Q1-1	2	0.4	850	891.38	1907.81	2.14	Well distributed
B1-2	2.5	0.5	421	660.79	690.07	2.13	Well distributed
Q1-3	2	0.34	429.31	740	1598.72	1.95	Moderately distributed
Q1-4	2	0.4	425.66	716	1402.53	1.8	Moderately distributed
Q1-5	2	0.42	421	696.57	976	2.08	Well distributed
Q2-1	2	0.4	700	822.82	1714.64	2.2	Well distributed
Q2-2	2.5	0.5	395	567.23	671.73	2.02	Well distributed
Q2-3	2.5	0.5	387	539.94	655.45	1.8	Moderately distributed
Q2-4	2.5	0.5	325	526.22	590	2.13	Well distributed
Q2-5	2.5	0.5	324.5	487.16	567.23	2.04	Well distributed
Q2-6	1.5	0.54	304.81	421.33	540	1.6	Moderately distributed
Q1-6	1.5	0.55	291.99	415.04	454.38	2.15	Moderately distributed
Q2-7	1.5	0.55	240	375.47	415.04	1.85	Moderately distributed
Q1-7	1.5	0.55	63.11	343.39	343.39	1.85	Moderately distributed
Q1-8	1.5	0.55	23.56	297.8	286.98	1.15	Fairly Distributed

The powder factor, representing the amount of explosive used per unit volume of rock, is crucial in controlling blast fragmentation size in mining and quarrying [8]. This study shows that, an optimal powder factor provides efficient energy transfer during detonation, influencing rock breakage and fragmentation patterns as shown in the X50, X20, and X80 sizes as shown in Figure 7.

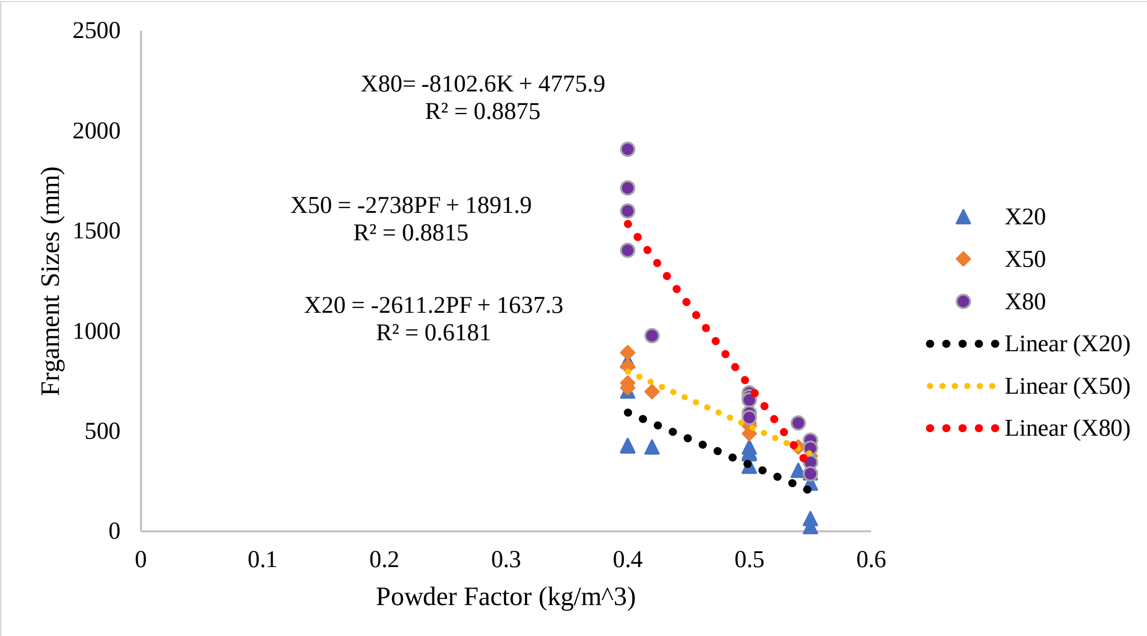


Figure 7: Blast fragment classification chart based on Powder Factor

Figure 7 presents the relationship between blast fragmentation size and explosive powder factor. The chart shows classification path for blasting output as a function of powder factor, it shows that the fragmentation size decreases with increase in the quantity of explosive used per tonnage.The correlation relationship between fragmentation size and powder factor was also established in this study. The finding shows that blast fragmentation size has strong correlation with powder factor. The linear correlation formula generated on the chart for X50, X20, and X20 has coefficient of correlation equal to 88.15%, 61.81%, and 88.75% respectively.

CONCLUSIONS

This study assesses rock explosive properties in chosen Lokoja quarries, Nigeria, aiming to characterize fragmentation. Findings from this work enhance blast operation for optimized downstream operation and productivity.

The following conclusions were drawn from the results of the analysis:

1. The result shows that the rock formation in Gitto quarry has the highest porosity and UCS value of 33% and 123 MPa respectively. The low permeability of both samples (1.2×10^{-17} m^2) also reveal significant advantage in the context of quarry material application.
2. The study revealed that Q2 (123 MPa) has higher compressive strength as compared to Q1 (120 MPa). The findings indicates that Q2 may be more resistant to crushing forces. This information is vital for determining the appropriate explosive energy required for efficient fragmentation.

3. The blast design parameter data from Q1 and Q2 show that the average values of various blast parameters, such as hole diameter is 10 m hole depth with a 1 m sub drill and a 2 m stemming height.
4. The fragmentation analysis result carried out in this study using WipFrag software shows that the 50%, 80% and Maximum block size passing size ranges from 539.94 – 1349.53 mm, 690.07 – 1907.81 mm, 808-2280 mm respectively. The blast fragmentation sizes are classified as moderate distribution blast based on the uniformity index value ranging from 1.95 to 2.4.
5. The relationship between blast fragmentation size and powder factor was evaluated using linear correlation coefficient. It was noted that, X20, X50, X80 has high R^2 values greater than 60% respectively.
6. Classification chart and Table was developed to provide easy use interpretation of blast fragmentation result.

Conflicts of interest
The authors declare no conflict of interest.

Ethical statement
Authors state that the research was conducted according to ethical standards.

Data Availability
Data will be made available on request

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