Assessment of Small Scale Mine Blast Toe Volume Effect on Fragmentation Size Distribution: An Application of Edge Detection Software

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Abstract: *This study explores the critical aspect of blast toe volume in small-scale mining operations and its impact on fragmentation size distribution. The assessment is conducted to understand the relationship between blast toe volume and the resultant blast design patterns. A comprehensive analysis is carried out using production blast result from four dolomite quarries in Akoko Edo, Nigeria, focusing on various explosive engineering parameters. The research employs advanced measurement techniques and statistical methods to quantify blast toe volume and assess its influence on fragmentation size distribution. By systematically varying blast toe volumes in controlled experiments, the study aims to establish correlations between toe volume and the resulting fragmentation size. The Variance inflation factor obtained in this study revealed that the selection of parameters during toe volume simulation must be carried out with respect to stemming length and explosive weight (MIC). The result shows that the maximum instantaneous charge has a negative correlation influence on toe volume as stemming also increases. This reveals that variation in stemming length results in low explosive energy release along the blast hole column, causing toe undulation. Finally, it was also revealed that at the blast mean size (X_{50}) increases, the toe also increases due to the poor utilization of explosive energy at the blast column.*

Keywords: small scale mining, Blasting, Toe Volume, WipFrag, Image analysis

INTRODUCTION

Small-scale mining is the extraction of minerals or resources on a restricted scale, usually by individuals or small organizations [1]. This mining business is crucial to the local economy, but it must be properly regulated. According to Oramah et al. [2], small-scale mining in Nigeria has a high potential for generating multiple benefits. This sector creates job opportunities, empowers local communities, and reduces poverty [2]. According to Laing and Pinto, this sector helps to diversify the economy and fosters resilience to economic shocks [3]. Small-scale mining can also help to encourage rural development by providing communities with access to basic facilities. Furthermore, it enables the use of hitherto unexplored mineral resources, which promotes economic growth, and when properly regulated, it has a lower environmental impact than large-scale activities. Furthermore, small-scale mining lacks appropriate skills and development advances, particularly in terms of efficient and productive use of explosive and blast productivity. According to Taiwo et al. [4], blasting operations in mining entail the controlled use of explosives to break rock, allowing for simpler excavation. The efficiency of these processes is governed by elements such as blast design, explosive type, and toe volume creation, which all have an impact on energy usage. Toe volume is the amount of unfragmented material at the base of a blast [5, 6]. Salmi et al. [7] observed that proper blast design takes into account geology, rock characteristics, and intended fragmentation. To improve blasting results, toe volume management is crucial to reducing energy waste and increasing fragmentation efficiency. To optimize blast fragmentation, this study examined the effect of toe volume on explosive energy utilization using a small-scale dolomite quarry as a case study.

Zhang et al. [8] stated that the global mining sector uses a significant amount of energy to reduce fragment size throughout the transition from mining to mineral processing, with very low energy efficiency, especially in ore crushing and grinding. Their research elucidates the impact of rock fragmentation through blasting on energy consumption, productivity, minerals' recovery, operational expenses throughout the entire size reduction process from mining to mineral processing, and the sustainability of the mining sector. The expense of blasting output significantly affects the feasibility of mining operations. Sazid and Singh [9] emphasized the importance of blast parameters, such as burden, in utilizing explosive energy. Research has demonstrated that the effectiveness of a blast is influenced by both the blast design and the mine floor profile. It is crucial to analyze the effect of toe volume on blast fragmentation in mining operations utilizing image analysis tools. Image analysis allows for accurate measurement and assessment of fragmented material, offering vital information for enhancing blast design [11–13]. Comprehending the relationship between toe volume and fragmentation is crucial for selecting appropriate blasting techniques, improving rock breaking efficiency, and minimizing energy wastage. The evenness of the pit bottom can impact the efficiency of mining operations once the blasted materials have been fully removed. Multiple research investigations have shown that having rocks in blasted mud can slow down downstream operating efficiency and have a detrimental effect on the costs associated with hauling, transporting, and processing. The quality and state of the pit bottom will significantly impact the cost and efficiency of fresh drilling and blasting activities. Drilling and blasting are excellent methods for removing rocks in mines, but they can cause environmental challenges such toe troubles, humps, and uneven pit floor elevation, as depicted in Fig. 1 from Golden Girl Quarry. This problem significantly affects blasting, overall production, tonnage, and cost, necessitating the necessity for secondary blasting. Hence, it is advantageous to evaluate the repercussions of this matter on small-scale mines. Accurate evaluations of blast output using image analysis help promote sustainable mining practices by optimizing resource use and reducing costs and environmental impact. This project aims to enhance blasting techniques in small-scale mines in

Nigeria to promote cost-effectiveness and sustainable mining operations. The results are expected to offer useful insights for improving blasting techniques to increase efficiency in small-scale mining operations. This research is important because it has the potential to enhance blast design tactics, resulting in better control over fragmentation. Studying the relationship between blast toe volume and fragmentation size distribution can help improve ore recovery procedures by reducing waste and optimizing resource efficiency. This study's evaluation of small-scale mine blast toe volume on fragmentation size distribution is expected to provide significant insights for mining operations and address environmental and safety issues in the sector.

Fig. 1 Evidence of toes after loading operation at the case stud quarry pit

Description of case study area

To construct a database for this research, four quarries were selected as the case study. The chosen quarries include Golden Girl Quarry (Q1) in Ikpeshi, HNF Global Resources Quarry (Q2) in Bekuma, Makana Limited Quarry in Atte (Q3), and Fanalou (Q4) in Enwan. All these quarries are situated in Akoko Edo, located in the south-south region of Nigeria. The case study region is a subset of the primary lithology component that constitutes the geological composition of Nigeria. There are four primary categories for classifying the basement rocks in this area. Fig. 2 shows the geological map depicting the formations of the case study.

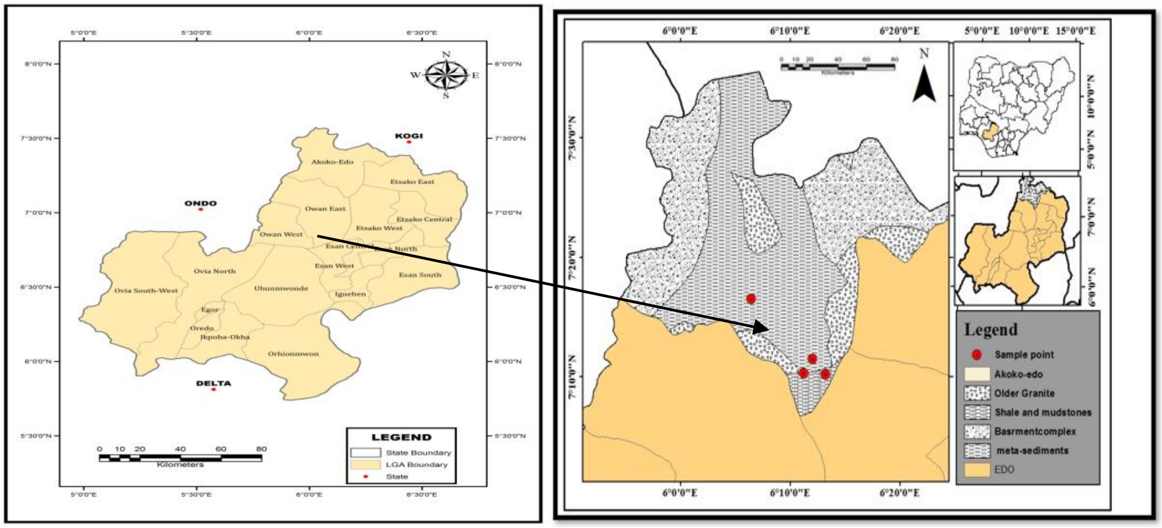


Fig. 2 Map of Edo State showing the location of Akoko Edo Local Government Area

METHODOLOGY

Geometric Blast Design Data

The blast design characteristics, such as burden, spacing, drill hole length, hole diameter, and stemming, were extracted from the blast plans and reports of the four quarries used in the case study. The geometric dataset was collected from four chosen quarries in Akoko Edo. The quarries utilize a square drilling design with a staggered layout.

Measurement of Blast Toe Volume and Blast Fragmentation

The blast toe volume was determined by accessing the pit floor of each mining site after the loading operation and before the drilling process. The volume of the intact rock outcrop above the pit floor was measured and recorded for each blast round design. Following each explosion, a standardized device was placed on the debris, and high-quality images were captured. These images were then transferred to a computer with WipFrag digital technology for analysis of particle sizes. The study utilized the WipFrag 4. Software for analyzing size distribution. Fig. 3 displays the outcome of the picture analysis. The blast parameters, fragmentation outcomes, and toe volume size were assessed by Multicollinearity analysis and linear correlation, as detailed in references [19] and [20].

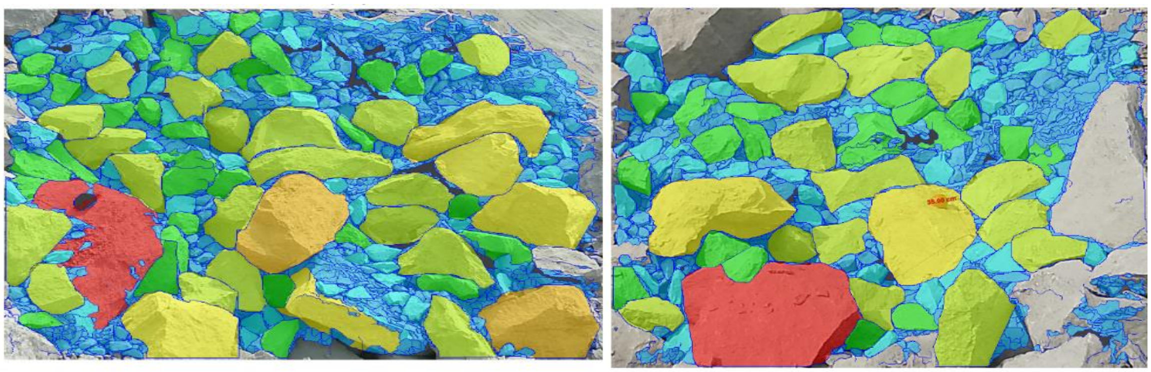


Fig.3 Image analysis edge detection result

RESULTS AND DISCUSSION

Collected Data Visualization and Interpretation

The blast design characteristics, such as burden, spacing, drill hole length, hole diameter, and stemming, were obtained from the blast plans and reports of the four quarries analyzed in the case study. The geometric dataset was obtained from four selected quarry sites in Akoko, Edo. The volume of the blast toe was determined by inspecting the pit floor of each mine site after loading explosives and before starting the next drilling operation. The volume of the undisturbed rock formation above the lower boundary of the excavation floor was measured and recorded for each explosive round setup. The explosive consumption factor in these operations ranged from 0.44 to 1.8 kg/m^3, as seen in Table 1. The blast toe volume was classified into four categories (difficult, challenging, moderate, low, and satisfactory) as displayed in Table 1.

Table 1: Dataset statistical analysis result and Toe Rating Number

	S (m)	B (m)	SB (m)	DHL (m)	SR	MIC (kg)	K (kg/m^3)	(V) (m^3)
Max	1.3	1.2	0.9	1.45	2	1.06	1.8	443.29
Min	0.7	0.6	0.29	0.7	1.07	0.51	0.44	107.67
Average	1.05	0.83	0.66	1.3	1.59	0.85	0.77	191.28
Stdev	0.11	0.1	0.09	0.08	0.19	0.1	0.2	51.2
Category		Toe Rating						
	>200	150-200	100-150	<100				
	4	3	2	1				
	Problematic	Challenging	Moderate	Good				

Relationship between Blast design parameters and Toe Volume

Multicollinearity arises when independent variables in a regression model exhibit strong correlation, making it challenging to evaluate their separate impacts on the dependent variable [21]. This study utilized the method to assess the correlation between controllable and uncontrollable blast parameters and the volume of toe measured post-blasting. Strong correlation or multicollinearity can reduce the credibility of statistical assessments concerning the influence of each blast component on their design parameters. The Variance inflation factor (VIF) was determined for each blast parameter in relation to toe volume size variation. Figure 6 displays the analysis results indicating that rock strength, spacing, and Maximum instantaneous charge exhibit low multicollinearity ($0 < VIF \leq 2$); burden, powder factor, and stemming length show significant multicollinearity ($2 < VIF \leq 4.0$); drill hole length demonstrates moderate multicollinearity ($5.0 < VIF \leq 15.0$); and Burden and stiffness ratio present a problematic level of multicollinearity ($VIF > 15.0$). The VIF result in Fig. 4 indicates that while simulating toe volume, parameter selection should include stemming length and explosive weight (MIC).

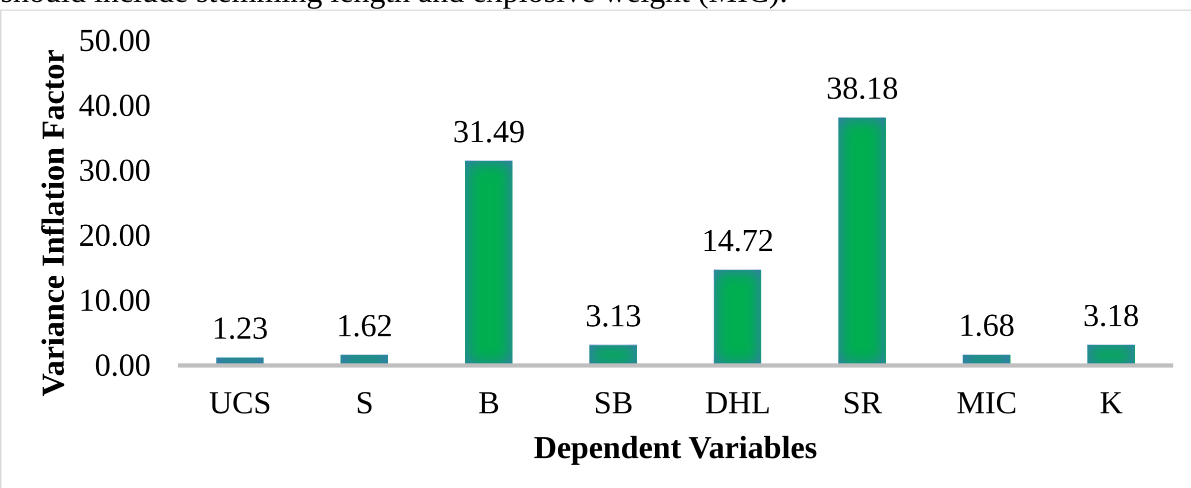


Fig. 4 Variance Inflation Factor for all Model Variables

The Maximum instantaneous charge and stemming length were correlated with toe volume size measure after blasting (see Fig. 5). The findings show that the maximum instantaneous charge has a negative correlation influence on toe volume as stemming also increases. This reveals that variation in stemming length results in low explosive energy release along the blast hole column, causing toe undulation.

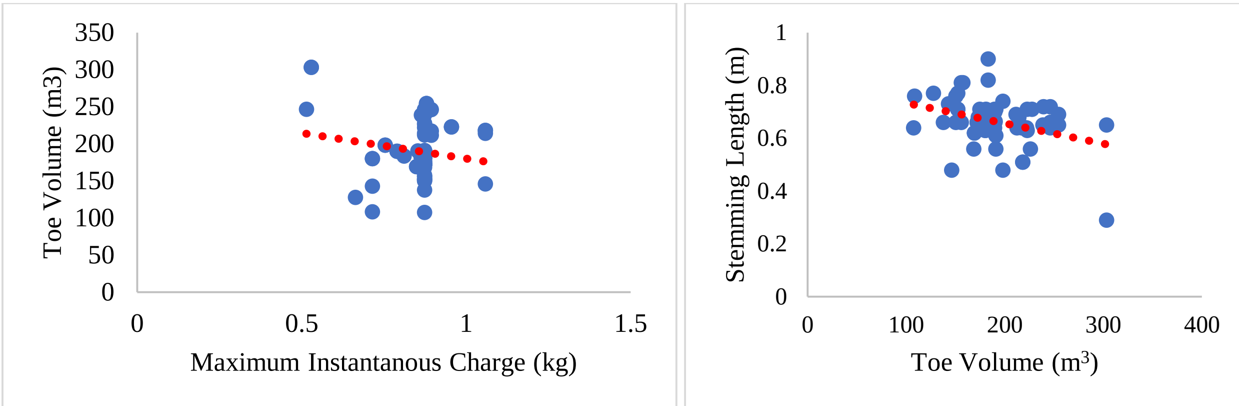
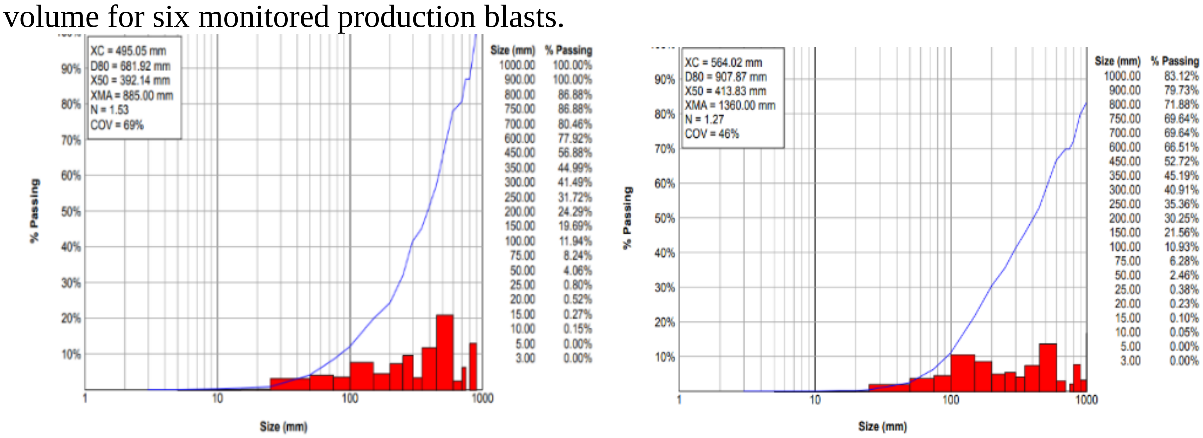


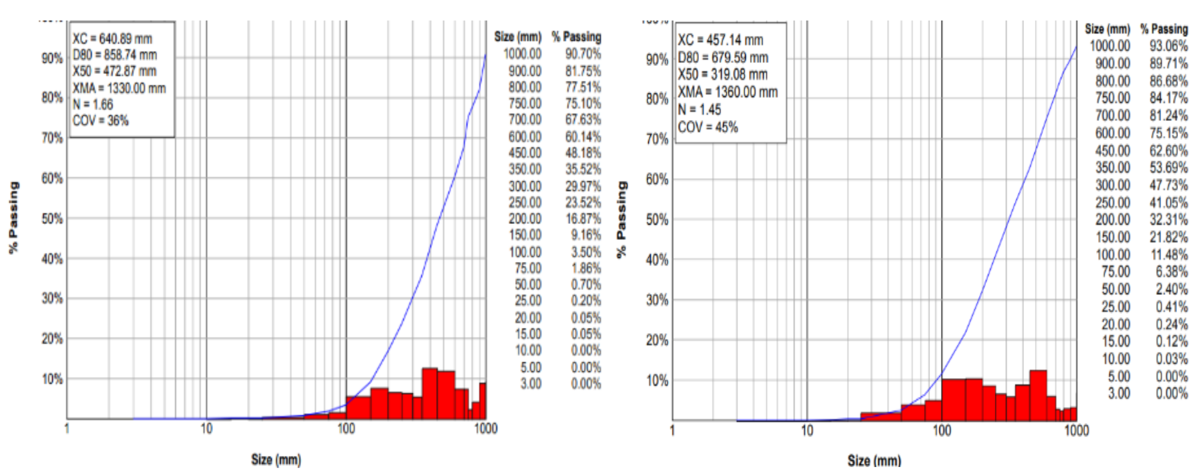
Fig. 5 Relationship between toe volume, maximum instantanous charge and stemming length

Assessing the Effect of Blast Toe on Fragmentation

Figs 6 and Table 2 presents the blast fragmentation mean size, uniformity index, and blast toe volume for six monitored production blasts.



a) b)



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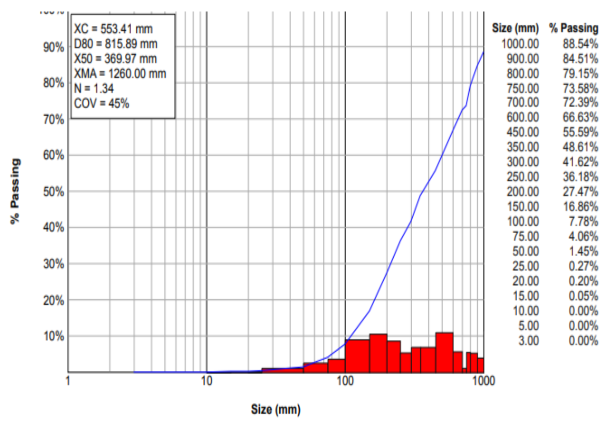

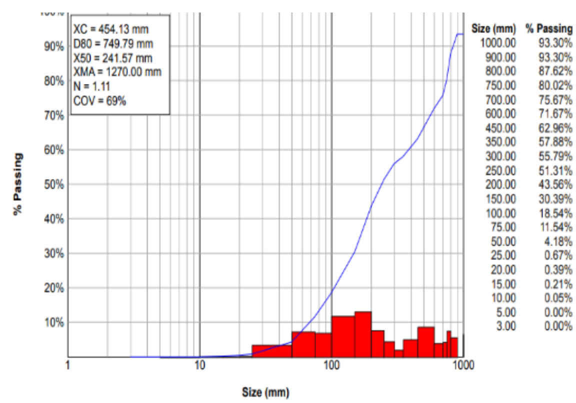

e) f)

Fig. 6 Blast size distribution for six blast result

Table 2: Fragmentation Result and Teo Volume measurement

Blast ID	X50 (mm)	N	TV (m^3)
BL-1	392.14	1.53	209.5
BL-2	413.83	1.27	196.6
BL-3	472.87	1.66	208.2
BL-4	319.08	1.45	158.6
BL-5	369.97	1.34	154.8
BL-6	241.57	1.11	159.5
X50 is the 50% passing size, N is the uniformity index, TV is the blast toe volume			

Fig. 7 present the relationship between uniformity index, mean fragmentation size and toe volume. The analysis shows that both uniformity index and mean fragmentation size has positive correlation with Toe volume size. The findings revealed that at the blast mean size (X_{50}) increases, the toe also increase due to the poor utilization of explosive energy at the blast column.

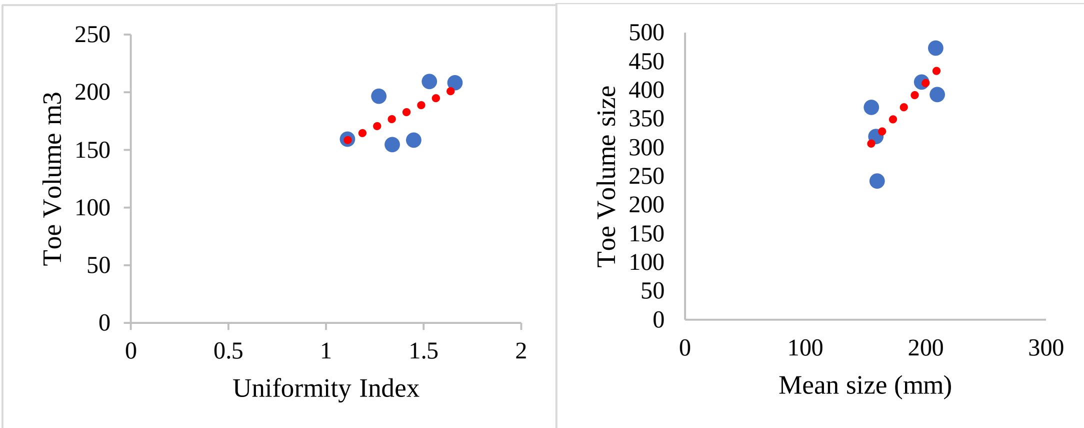

Fig. 7 Relationship between Toe volume size, mean fragmentation size and uniformity index

CONCLUSIONS

Assessing the volume of a blast toe is essential in explosive engineering to gauge the impact and potential damage. Precise volume measurement is crucial for risk assessments, safety planning, and infrastructure protection. This study evaluates the correlation between blast design parameters, fragmentation size, and toe volume size. Four quarries in Akoko Edo, Nigeria were selected as the focus of the investigation. The explosion fragmentation size after each round was recorded and analyzed using WipFrag version 4. The Toe volume resulting from six blast rounds was measured and recorded using the WipFrag analysis results. The relationship between blast parameters and toe volume size was evaluated by analyzing the variance inflation factor. The results indicate that the quantity of explosives, burden, and stemming length have a substantial effect on the volume of the toe. The WipFrag results were associated with toe volume, indicating that the size of the toe volume greatly affects the distribution of fragmentation sizes.

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

References

[1]. Zvarivadza, T. (2018). Artisanal and Small-Scale Mining as a challenge and possible contributor to Sustainable Development. *Resources Policy*, *56*, 49-58.

[2]. Oramah, I. T., Richards, J. P., Summers, R., Garvin, T., & McGee, T. (2015). Artisanal and small-scale mining in Nigeria: Experiences from Niger, Nasarawa and Plateau states. *The Extractive Industries and Society*, *2*(4), 694-703.

[3]. Laing, T., & Pinto, A. N. (2023). Artisanal and small-scale mining and the low-carbon transition: Challenges and opportunities. *Environmental Science & Policy*, *149*, 103563.

[4]. Taiwo, B. O., Fissha, Y., Palangio, T., Palangio, A., Ikeda, H., Cheepurupalli, N. R., ... & Kawamura, Y. (2023). Assessment of Charge Initiation Techniques Effect on Blast Fragmentation and Environmental Safety: An Application of WipFrag Software. *Mining*, *3*(3), 532-551.
[5]. Kabwe, E. (2018). Velocity of detonation measurement and fragmentation analysis to evaluate blasting efficacy. *Journal of rock Mechanics and geotechnical Engineering*, *10*(3), 523-533.
[6]. Sadeghi, F., Monjezi, M., & Jahed Armaghani, D. (2020). Evaluation and optimization of prediction of toe that arises from mine blasting operation using various soft computing techniques. *Natural Resources Research*, *29*, 887-903.
[7]. Salmi, E. F., & Sellers, E. J. (2021). A review of the methods to incorporate the geological and geotechnical characteristics of rock masses in blastability assessments for selective blast design. *Engineering Geology*, *281*, 105970.
[8]. Zhang, Z. X., Sanchidrián, J. A., Ouchterlony, F., & Luukkanen, S. (2023). Reduction of fragment size from mining to mineral processing: a review. *Rock Mechanics and Rock Engineering*, *56*(1), 747-778.
[9]. Sazid, M., & Singh, T. N. (2015). Numerical assessment of spacing–burden ratio to effective utilization of explosive energy. *International Journal of Mining Science and Technology*, *25*(2), 291-297.
[10]. Eremenko, A. (2017, March). Blast design for improved performance and reduced surface vibration–a case study. In *Deep Mining 2017: Proceedings of the Eighth International Conference on Deep and High Stress Mining* (pp. 961-974). Australian Centre for Geomechanics.
[11]. Maerz, N. H., Palangio, T. C., & Franklin, J. A. (2018). WipFrag image based granulometry system. In *Measurement of Blast Fragmentation* (pp. 91-99). Routledge.
[12]. Hunter, G. C., McDermott, C., Miles, N. J., Singh, A., & Scoble, M. J. (1990). A review of image analysis techniques for measuring blast fragmentation. *Mining Science and Technology*, *11*(1), 19-36.
[13]. Taiwo, B. O., & Adebayo, B. (2023). Improvement of Blast-induced Fragmentation Using Artificial Neural Network and BlastFrag© Optimizer Software. *Materials and Geoenvironment*, *69*(1), 1-13.
[14]. Tang, H. L., Yang, J., & Yu, Q. (2023). Experimental Investigation of the Effect of Delay Time on Rock Fragmentation in Multi-Hole Bench Blasting. *Applied Sciences*, *13*(12), 7329.
[15]. Shehu, S. A., Yusuf, K. O., Zabidi, H., Jimoh, O. A., & Hashim, M. H. M. (2023). Blasting efficiency in granite aggregate quarry based on the combined effects of fragmentation and weighted environmental hazards. *Mining of Mineral Deposits*, *17*(1).
[16]. Taiwo, B. O., Famobuwa, O. V., Mata, M. M., Sazid, M., Fissha, Y., Jebutu, V. A., ... & Abubakar, O. (2024). Granite Downstream Production Dependent Size and Profitability Assessment: an application of Mathematical-based Artificial Intelligence Model and WipFrag Software. *Journal of Mining and Environment*, *15*(2), 497-515.

[17]. Bui, X. N., Nguyen, H., Le, H. A., Bui, H. B., & Do, N. H. (2020). Prediction of blast-induced air over-pressure in open-pit mine: assessment of different artificial intelligence techniques. *Natural Resources Research*, *29*(2), 571-591.
[18]. Taiwo, B. O., & Omotehinse, A. O. (2022). The economic potential of some metacarbonate rocks in Akoko-Edo, Edo state Nigeria. *Applied Earth Science*, *131*(3), 167-178.
[19]. Alin, A. (2010). Multicollinearity. *Wiley interdisciplinary reviews: computational statistics*, *2*(3), 370-374.
[20]. Daoud, J. I. (2017, December). Multicollinearity and regression analysis. In *Journal of Physics: Conference Series* (Vol. 949, No. 1, p. 012009). IOP Publishing.
[21]. Paul, R. K. (2006). Multicollinearity: Causes, effects and remedies. *IASRI, New*