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Optimizing rock fragmentation in open pit mining: Blasting plan refinement using WipFrag and Kuz-Ram method

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Summary

In open-pit mining, optimizing blasting techniques is essential for enhancing both operational efficiency and achieving desired rock fragmentation, which directly impacts subsequent processes such as loading, hauling, and crushing. A well-designed drilling pattern and precise blasting plan are crucial for ensuring the effective distribution of block sizes. The technical and geometrical characterization of rock fragments plays a key role in improving blasting performance. This study focuses on enhancing fragmentation quality in the ENG Ain Touta limestone quarry, NE of Algeria, through the application of numerical modeling techniques. Current blasting outcomes were evaluated using WipFrag software to create particle size distribution curves, which revealed a significant proportion of oversized blocks, ranging between 21% and 25%. This highlights a critical need for modifications to the blasting plan. To address this, a revised plan was developed, incorporating an additional 20 kg of explosives per borehole. The predicted effects of this adjustment were modeled using the Kuz-Ram method, showing a 40% reduction in oversized blocks and a substantial improvement in rock fragmentation quality. The results underscore the effectiveness of integrating image analysis software and predictive modeling in refining blasting strategies. By improving fragmentation, this approach can significantly boost mining operations' efficiency, reduce the handling of oversized materials, and optimize the overall quarrying process. This study demonstrates the potential of numerical models and targeted adjustments in blasting plans to enhance productivity and cost-effectiveness in open-pit mining operations.

Keywords

optimization • blasting plan design • blasting • drilling pattern • oversized blocks

1. Introduction

Minerals, including rocks, soil, and metals, have been essential to the advancement of human civilization. Projections indicate that global demand for these materials could double in the next forty years, potentially reaching 167 billion tons annually, up from 90 billion tons in 2018. This translates to about 45 kilograms of materials per person per day [Tabet et al. 2019, 2020, Jacque 2018, Batouche 2019, Fredj et al. 2020, Mahleb et al. 2022, Brahmi et al. 2023]. Consequently, the mining industry is a vital sector, not only due to its economic significance but also because of its considerable social and environmental impacts at both local and global scales [Zeqiri et al. 2019, Zerzour et al. 2020, 2021, Maksym and Khomenko 2021, Taib et al. 2023]. Among various extraction methods, blasting is one of the most widely used techniques in open-pit mines and quarries for fragmenting hard rock [Driss et al. 2023, Ellouze et al. 2023, Charrak et al. 2024, Bakhtaoui 2024]. Success in mining operations heavily relies on effective drilling and blasting, as these processes directly affect the quality of rock fragmentation and subsequent activities such as loading, transport, and crushing [Kanchibotla et al. 1999, Monjezi et al. 2008].

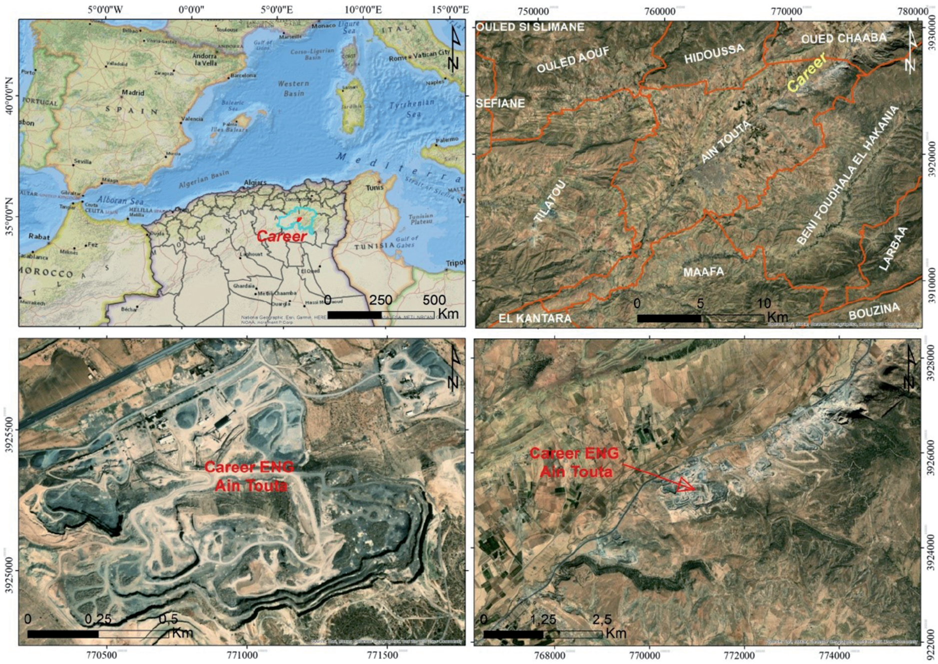
Scientific research has shown that the stages of mineral production are highly interdependent, with blasting outcomes significantly impacting the efficiency of downstream processes [Eloranta 1995, Simkus and Dance 1998]. In particular, optimizing rock fragmentation can eliminate the need for secondary handling of oversized materials while minimizing the production of undesirable fines [Hüdaverdi and Akyildiz 2020]. To achieve optimal fragmentation, mining engineers employ various techniques and models to fine-tune blasting parameters. Assessing and predicting fragmentation quality is crucial for enhancing operational efficiency [Babaeian et al. 2019]. Indirect methods, such as image analysis, provide accurate means to determine the particle size distribution of fragmented rocks using specialized software like WipFrag and Split-Desktop [Nanda et al. 2020].

A well-structured blasting plan in open-cast limestone and dolostone quarries involves the controlled use of explosives to ensure efficient and safe rock fragmentation. This plan focuses on borehole placement, appropriate explosive charges, precise detonation timing, and understanding of the geological properties of the rock. An optimized blasting strategy improves fragmentation, reduces the occurrence of oversized blocks, and enhances both safety and cost-effectiveness in quarry operations.

In the ENG Ain Touta aggregate quarry in northeast Algeria, the existing blasting plan leads to a high proportion of oversized blocks, necessitating costly additional interventions and diminishing overall productivity. This study seeks to optimize blasting techniques by employing numerical modeling to improve rock fragmentation quality and decrease the percentage of oversized blocks.

2. General setting

The production of aggregates in Algeria is managed by various private and public companies, including the National Aggregate Company (ENG). This company manages the production, marketing and development of aggregates, calcium carbonate and ornamental stones. The ENG Ain Touta quarry in Batna (the North-East of Algeria), is one of the main quarries in the country, it has been operating in limestone since 1978, producing more than 1,000,000 tonnes of aggregates per year, used in construction and public works [Moueri et al. 2024]. The ENG Ain Touta limestone deposit is located 23 km southwest of Batna and 12 km northeast of Ain Touta, on the northern slope of Djebel Bled Tafrent (Fig. 1). The site is characterized by an altitude ranging from 1000 to 1120 m. Morphologically, the southern part of the deposit features a relatively flat surface traversed by shallow ravines oriented southwards. To the west, east, and north, the slopes become steeper, sometimes forming cliffs that overlook the El Ksour valley.



Source: Authors' own study

Fig. 1. Location map of the study area

The regional stratigraphic sequence spans from the Triassic to the Quaternary. The Triassic, consisting of limestones and marls, outcrops in small areas north of Batna. The Jurassic, subdivided into lower, middle, and upper levels, is composed of massive limestones, shales, and clays, and primarily outcrops northeast of Batna. The Cretaceous, also subdivided into three levels, outcrops to the north, northwest, and southeast of Batna, with a predominance of Turonian limestones of the Middle Cretaceous in the studied deposit (Fig. 2). The Tertiary is represented by Miocene formations (sandstones, clays, rare limestones) located southeast of Batna. Finally, the Quaternary is dominated by alluvial deposits along the El Ksour valley and at the foot of the Djebels.

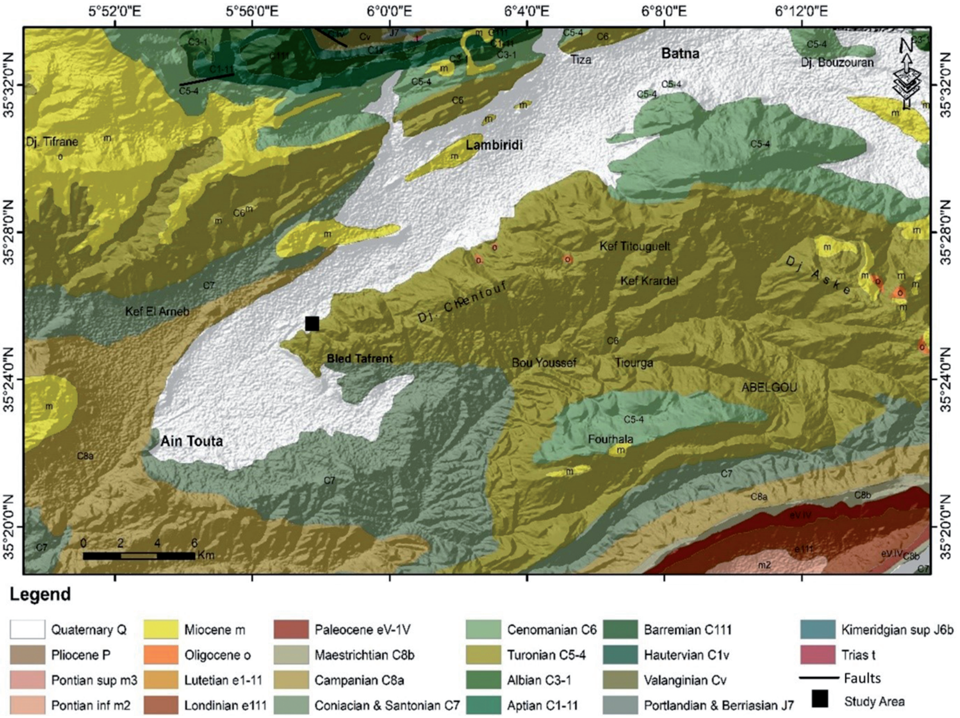


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Fig. 2. Geological map of the study area

The main physical and mechanical characteristics of the limestone under the conditions of our case study are presented in Table 1.

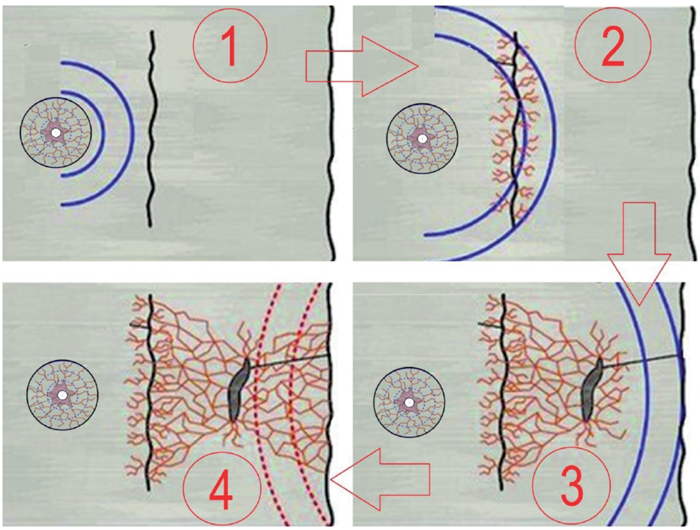
Table 1. Main physical and mechanical characteristics of the limestone rock in the case study

No.	Characteristic	Unit	Value	No.	Characteristic	Unit	Value
01	Specific weight of solids	kN/m^3	25.5	05	Micro Deval	%	13.41

02	Water content	%	0.46	06	Los Angelos	%	24.94
03	Absorption	%	0.48	07	Hardness	–	06-07
04	Porosity	%	3.01	08	Resistance to compression	Mpa	6-10

3. Materials and methods

Explosive rock fragmentation is a complex dynamic process that depends on the interaction between the rock mass and the explosives used [Siddiqui et al. 2009]. This process can be described in several stages: the decomposition of explosives into gases under high pressure and temperature, the propagation of stress waves through the rock mass, the fracturing or damage of the rock, the expansion of gases through the created weak zones, the opening of cracks, followed by the movement and ejection of fragments [Mouloud 2017, Yang et al. 2018] (Fig. 3).



Source: Škrlec et al. [2014] (modified)

Fig. 3. An illustrative diagram summarizes the essential steps of blasting in rocks: 1. hole radius; 2. radial cracking; 3. elastic limit; 4. ductile deformation and fragmentation

After each blasting operation, the results of the fragmentation must be analyzed and interpreted to adjust the parameters of the blasting plan, with the aim of achieving optimal fragmentation. Since direct methods of fragmentation evaluation are costly and limited, indirect approaches are often used to estimate the particle size distribution of the blasted rock fragments. In this study, we used the Kuz-Ram empirical model and the digital image-based method with WipFrag software to analyze the particle size distribution of fragmented rocks in the ENG Ain Touta quarry.

3.1. Use of WipFrag Software

WipFrag software, developed by Wipware, is widely recognized for analyzing images of fragmented rocks [Maerz et al. 2018, Zhang et al. 2021, Saadoun et al. 2022]. This method involves capturing images of the rock pile in the field using a scale reference device, then processing these images to identify individual blocks and create a contour network. These images are then converted into volumes and weights of fragments, and the results are displayed as graphs representing the particle size distribution [Tosun 2018].

3.2. Empirical Model Kuz-Ram

The Kuz-Ram model, originally developed by Kuznetsov [1973] and improved by Cunningham [1983, 1987, 2005], is an essential tool for estimating the average size of fragments ($X_m = X_{50}$) and the uniformity index of fragmentation. This model uses key parameters such as rock properties, explosive characteristics, and blasting plan design parameters [Shehu et al. 2020, 2022]. The equations (1), (2) and (3) summarize the operation of the Kuz-Ram model:

- **Mean size fragments of muckpile ($X_m = X_{50}$), m**:

$$X_{50} = A(PF)^{-0.8} Q^{0.167} \left(\frac{115}{RWS_{ANFO}} \right)^{0.633} \tag{1}$$

- **Size distribution curve:**

$$R(X) = 1 - e^{-\left(\frac{x}{x_c}\right)^n} \tag{2}$$

- **Uniformity index:**

$$n = \left(2.2 - 14\frac{B}{D} \right) \left(\frac{1 + \left(\frac{S}{B} \right)^{0.5}}{2} \right) \left(1 - \frac{E_p}{B} \right) \left(\frac{L}{BH} \right) \tag{3}$$

where:

A	–	the rock factor,
PF	–	the specific charge [kg/m³],
Q	–	the charge mass per blast holes [kg],
RWS_{ANFO}	–	the relative weight strength of the explosive to ANFO [%],
E_p	–	the blast holes deviation.

3.3. Experimental procedure

To evaluate the size distribution of blasted rocks, data were collected from two blasts in the ENG Ain Touta quarry. Images of the rock piles were taken and then analyzed using

WipFrag. Next, modifications were made to the blasting plan to improve fragmentation, and the anticipated results were modeled using Kuz-Ram. Finally, a comparison was made between the practical results obtained in the field with WipFrag and the predictions from the Kuz-Ram model to validate the relevance of the proposed adjustments.

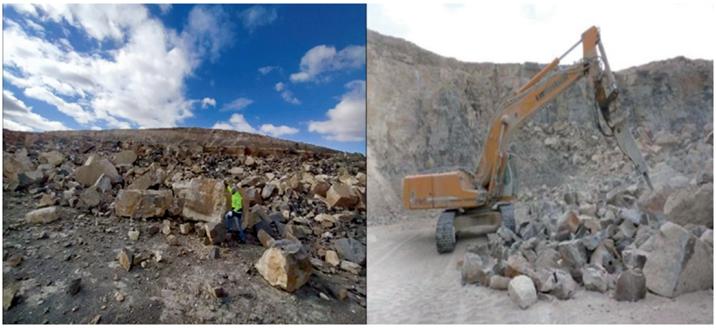
4. Results and discussion

In order to improve the quality of fragmentation at the aggregate quarry of ENG Ain Touta, we studied two blasting tests with the same blasting plan parameters. The quarry operates with benches of 15 m in height and 80° of dip angle. The holes drilled with percussion with blast holes diameter of 110 mm. Each hole is loaded with 25 kg of Marmanite III and approximately 30 kg of Anfomile per hole for a total explosive quantity in the blast hole Q equal to 55 kg, with a charge density of explosive K. The blast design parameters used in the ENG limestone quarry are essential to optimizing the efficiency of blasting operations. The hole diameter (D) is set at 110 mm, allowing for sufficient space to load the explosives. The face dip direction, set at an 80-degree angle, influences the direction of the blast and ensures proper fragmentation. The burden (B), which is the distance between the blast holes and the free face, is 3 meters, while the spacing (S) between the blast holes is 4 meters, ensuring adequate distribution of the explosive energy. Sub-drilling (SD) is measured at 1 meter, which helps prevent unbroken rock at the bottom of the blast. The stemming height (SH), which refers to the inert material placed above the explosive charge to contain the energy, is set at 7 meters. The hole depth (HD) is 16 meters, with the bench height (BH) being 15 meters, ensuring that the drilling depth corresponds to the bench height for optimal blast performance. The specific charge or powder factor (k) is 0.31 kg/m^3, which indicates the amount of explosive used relative to the volume of rock to be broken. The charge weight per hole (Q) is 55 kg, carefully calculated to balance effective fragmentation with safety. The column charge length (C), representing the upper part of the explosive column, is 5 meters, while the bottom charge length (Bot) is 4 meters, providing a controlled release of energy for efficient rock breakage.

Generally, blasting operations produce oversized rock fragments known as 'oversized blocks'. To reduce the size of these blocks at the ENG Ain Touta quarry, the secondary breaking is performed, either using explosives or by using rock breakers (Fig. 4), which incurs additional costs for the company.

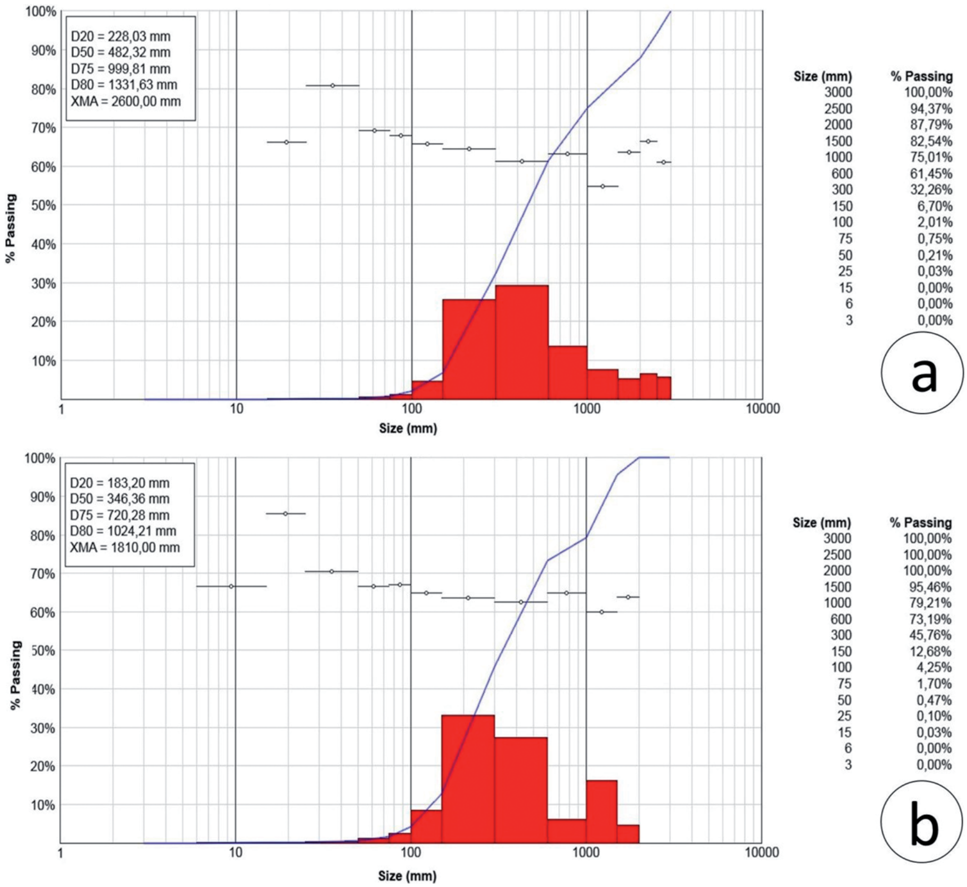
In the ENG Ain Touta quarry, the maximum acceptable fragment size that the primary crusher can handle is 1000 mm. The results of the particle size distribution of the blasted rocks, obtained from the two explosive blasts conducted and analyzed with WipFrag software, are presented in Figures 5a, and b.

The results of the particle size distribution of the blasted rocks, obtained from the blasting plan of the ENG Ain Touta quarry and the proposed blasting plan, modeled using the Kuz-Ram model, are presented in Table 2 and Figure 6 compares the Kuz-Ram model results with those obtained from WipFrag software.



Source: Authors' own study

Fig. 4. Oversized blocks on the studied site and the secondary breaking process



Source: Authors' own study

Fig. 5. a. WipFrag analysis of the blasted rocks of blast 01; b. WipFrag analysis of the blasted rocks of blast 02

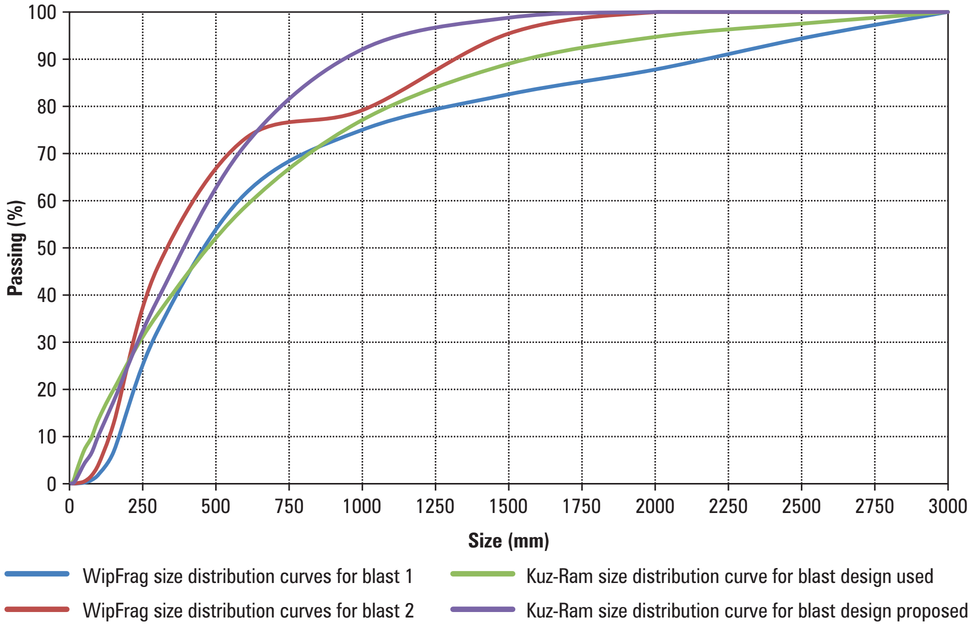
Figure 5a shows that D20 is 228.03 mm, D50 is 482.32 mm, and D80 is 1331.61 mm. The rate of oversized blocks is 24.99%. Whereas Figure 5b shows that D20 is 183.20 mm, D50 is 346.36 mm, and D80 is 1024.21 mm. The rate of oversized blocks is 20.79% (Table 3).

Table 2. Comparison of applied vs predicted fragmentation in Kuz-Ram Blast Plan Design

Predicted fragmentation	Applied blast plan	Proposed blast plan designed with Kuz-Ram (Q = 75 kg)
Percent oversize (Maximum percentage)	23.0%	7.9%
Percent in range (Average percentage)	75.5%	91.6%
Percent undersize (Minimum percentage)	1.5%	0.5%

Table 3. Result of percentage passing for WipFrag and Kuz-Ram analyses

Size [mm]	Passing [%]			
	WipFrag		Kuz-Ram (Blast plan used)	Kuz-Ram (Blast plan proposed)
	Blast 1	Blast 2		
0	0.00	0.00	0.00	0.00
3	0.00	0.00	0.00	0.00
6	0.00	0.00	0.00	0.00
15	0.00	0.03	0.90	0.20
25	0.03	0.10	2.90	1.20
50	0.21	0.47	7.10	4.20
75	0.75	1.70	9.80	6.50
100	2.01	4.25	13.80	10.40
150	6.70	12.68	19.90	17.40
300	32.26	45.76	35.80	38.90
600	61.45	73.19	58.70	71.80
1000	75.01	79.21	77.10	92.10
1500	82.54	95.46	89.00	98.80
2000	87.79	100	94.70	100
2500	94.37	100	97.50	100
3000	100	100	100	100



Source: Authors' own study

Fig. 6. Kuz-Ram of proposed blast plan design compare Kuz-Ram of used blast plan design and WipFrag size distribution curves

The results obtained using the WipFrag image processing software and the Kuz-Ram prediction model show a notable convergence in the percentages of rocks, both for large blocks and fines. However, a slight variation is observed for other dimensions, likely due to the heterogeneity of the rock mass. This variation indicates that the implementation of the blasting plan in the field resulted in a percentage of 25% of oversized blocks, which can be attributed to an insufficient amount of explosives. This result has significant consequences for the company, including a decrease in annual yield, increased costs associated with secondary breaking operations, and a loss of time related to this process.

On the other hand, the results obtained with the Kuz-Ram model for an optimized blasting plan show a substantial improvement, with only 8% of oversized blocks. This improvement was achieved by increasing the amount of explosives per hole by more than 20 kg compared to the amount initially used by the company. This optimization reduced the proportion of large blocks to 40%, thus achieving values closer to the desired objectives.

5. Conclusion

This study assessed the quality of rock fragmentation through two blasting tests at the ENG Ain Touta limestone quarry in Batna, northeastern Algeria. Digital image analysis using WipFrag software revealed a significant portion of oversized materials, nearly 25% in the studied blasts, indicating suboptimal fragmentation caused by an insufficient explosive charge. To address this, a revised blast plan with an increased explosive charge was proposed. The results were validated using the Kuz-Ram model, which demonstrated that the optimization reduced the percentage of oversized blocks from 25% to 8%, meeting the industrial particle size requirements. The comparison between the particle size distribution curves obtained from WipFrag and the Kuz-Ram model showed strong agreement for large blocks and fines, with minor discrepancies for other sizes, likely due to the heterogeneity of the rock mass. This study confirms the importance of optimizing explosive charges to enhance fragmentation quality and underscores the effectiveness of integrating image analysis with predictive models in quarry blasting operations.

References

Babaeian M., Ataei M., Sereshki F., Sotoudeh F., Mohammadi S. 2019. A new framework for evaluation of rock fragmentation in open pit mines. Journal of Rock Mechanics and Geotechnical Engineering, 11(2), 325–336.

Bakhtaoui Y. 2024. Transformation of the Equivalent Linear Method for solving soil-structure interaction problems in the time domain. Journal of Geomechanics and Geoengineering, 2, 7–14.

Batouche T. 2019. Caractérisation et traitement du minerai Barytique d'Ain Mimoun pour l'obtention d'un concentre de haute qualité, Doctoral thesis. Echahid Cheikh Larbi Tébessi University Tébessa, Algeria.

Brahmi S., Fehdi C., Hadji R., Brahmi S., Hamad A., Hamed Y. 2023. Karst-induced sinkhole detection using a tomography imaging survey. Case of Setifian high plain, NE Algeria. Geotechnical and Geological Engineering, 41(3), 1961–1976.

Charrak H., Smail N., Rouissat B., Basri H., Alsamawi A.B. 2024. Analysis of upstream slope stability during rapid drawdown-Sidi Abdelli dam as a case study. Journal of Geomechanics and Geoengineering, 2, 1–6.

Driss A.A.E., Harichan K., Ghrici M. 2023. Effect of lime on the stabilization of an expansive clay soil in Algeria. Journal of Geomechanics and Geoengineering, 1, 1–10.

Ellouze S., Mezni N., Bouassida M. 2023. Ground Improvement – Selected Tunisian Case Histories. Journal of Geomechanics and Geoengineering, 1, 27–37.

Eloranta J. 1995. Selection of powder factor in large diameter blastholes. EXPLO 95 Conference, AusIMM, Brisbane, September, 25–28.

Fredj M., Hafsaoui A., Riheb H., Boukarm R., Saadoun A. 2020. Back-analysis study on slope instability in an open pit mine (Algeria). Natsional'nyi Hirnychyi Universytet. Naukovyi Visnyk, 2, 24–29.

Hüdaverdi T., Akyildiz Ö. 2020. Investigation of blast fragmentation models in a sandstone quarry. Bilimsel Madencilik Dergisi, 59(3), 145–156.

Jacque M. 2018. La consommation mondiale de matières premières va doubler d'ici à quarante ans. Les Echos. https://www.lesechos.fr/2018/10/la-consommation-mondiale-de-matieres-premieres-va-doubler-dici-a-quarante-ans-979959.

Kanchibotla S.S., Valery W., Morrell S. 1999. Modelling fines in blast fragmentation and its impact on crushing and grinding, Explo-99, Kalgoorlie.

Maerz N.H., Palangio T.C., Franklin J.A. 2018. WipFrag image based granulometry system. In: Measurement of Blast Fragmentation. Routledge, 91–99. https://doi.org/10.1201/9780203747919-15.

Mahleb A., Hadji R., Zahri F., Boudjellal R., Chibani A., Hamed Y. 2022. Water-borne erosion estimation using the revised universal soil loss equation (RUSLE) model over a semiarid watershed: Case study of Meskiana Catchment, Algerian-Tunisian border. Geotechnical and Geological Engineering, 40(8), 4217–4230.

Maksym K., Oleh K. 2021. New theory for the rock mass destruction by blasting. Mining of Mineral Deposits, 15, 2, 111–123. https://doi.org/10.33271/mining15.02.111.

Monjezi M., Dehghani M., Dehghani H. 2008. Optimization of blast pattern using neural networks in Chandermoul iron ore mine. Proceedings of the 26th International Geosciences Congress (in Persian).

Moueri A., Hadji R., Zahri F., Hamed Y., Serhane B. 2024. Multidisciplinary evaluation of geological, geotechnical, geomechanical, and hydrogeological parameters for assessing slope stability in the Aures Mountain Quarry. Geomatics, Landmanagement and Landscape, 2, 195–216. https://doi.org/10.15576/GLL/2024.2.14

Mouloud N. 2017. Etude d'un modèle de mesure de la fragmentation par le tir. Doctoral dissertation. University of Badji Mokhtar Annaba, Algeria.

Nanda S., Pal B.K. 2020. Analysis of blast fragmentation using WipFrag. J. Image, 5(6).

Saadoun A., Fredj M., Boukarm R., Hadji R. 2022. Fragmentation analysis using digital image processing and empirical model (KuzRam): A comparative study. J. Min. Inst., 257, 822–832. https://doi.org/10.31897/PMI.2022.84.

Shehu S.A., Hashim M.H.M. 2020. Evaluation of blast fragmentation and its benefits: a review of the paradigm and ambiguity', Int. J. Mining and Mineral Engineering, Vol. 11, No. 4, pp.338–358.

Shehu S.A., Yusuf K., Hashim M. 2022. Comparative study of WipFrag image analysis and Kuz-Ram empirical model in granite aggregate quarry and their application for blast fragmentation rating. Geomech. Geoeng., 17, 197–205.

Siddiqui F.I., Ali Shah S.M., Behan M.Y. 2009. Measurement of size distribution of blasted rock using digital image processing. Eng. Sci., 20(2), 81–93.

Simkus R., Dance A. 1998. Tracking hardness and size: Measuring and monitoring ROM ore properties at Highland valley copper. Proc. Mine to Mill Conf., Brisbane. Fourney W.L., Dick R.D. (eds.), 521–530.

Škrlec V., Dobrilović M., Bohanek V. 2014. Theories of rock breakage with explosives. Rudarsko-geološko-naftni zbornik, 29(1), 57–68.

Tabet A., Benyoucef A.A., Zerzour O., Batouche T., Achour Z.E. 2024. Analysis and improvement of the fragmentation quality of blasted rock using digital image processing: the case of the Kef Lahmer quarry, N-E Algeria. Geomatics, Landmanagement and Landscape, 1, 87–99. http://dx.doi.org/10.15576/GLL/2024.1.06

Tabet A., Nouioua I., Fehdi C., Zerzour O., Mehidi Y. 2019. Contribution to the analysis of the stability of an open pit mine: Case of the Kef Essnoun phosphate mine, Tebessa north-east Algeria. Journal of Fundamental and Applied Sciences, 11(3), 1344–1353.

Taib H., Hadji R., Hamed Y. 2023. Erosion patterns, drainage dynamics, and their environmental implications: a case study of the hammamet basin using advanced geospatial and morphometric analysis. Journal of Umm Al-Qura University for Applied Sciences, 1–16.

Tosun A. 2018. A modified WipFrag program for determining muckpile fragmentation. Journal of the Southern African Institute of Mining and Metallurgy, 118, 10, 1113–1199. http://dx.doi.org/10.17159/2411-9717/2018/v118n10a13

Yang R., Ding C., Yang L., Lei Z., Zhang Z., Wang Y. 2018. Visualizing the blast-induced stress wave and blasting gas action effects using digital image correlation. International Journal of Rock Mechanics and Mining Sciences, 112, 47–54.

Zeqiri R.R., Riheb H., Karim Z., Younes G., Rania B., Aniss M. 2019. Analysis of safety factor of security plates in the mine 'Trepça' Stantërg. Mining Science, 26, 21.

Zerzour O., Gadri L., Hadji R., Mebrouk F., Hamed Y. 2020. Semi-variograms and kriging techniques in iron ore reserve categorization: application at Jebel Wenza deposit. Arabian Journal of Geosciences, 13(16), 820.

Zerzour O., Gadri L., Hadji R., Mebrouk F., Hamed Y. 2021. Geostatistics-based method for irregular mineral resource estimation, in Ouenza iron mine, Northeastern Algeria. Geotechnical and Geological Engineering, 39(5), 3337–3346.

Zhang Z.X., Chi L.Y., Yi C. 2021. An empirical approach for predicting burden velocities in rock blasting. Journal of Rock Mechanics and Geotechnical Engineering, 13, 4, 767–773. http://dx.doi.org/10.1016/j.jrmge.2021.04.004.