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Research paper

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Blast design and improvement of the quality of fragmentation in the aggregate quarries. Case study: Djebel Bouzegza C01

Khaoula Bedri[1, ✉]
Mohamed Aguid Bachar Assed[1] 0000-0002-4245-476X
Hassan Taib[2] 0000-0001-7990-2258
Riheb Hadji[3] 0000-0002-9632-0812
Nabil Defaflia[4] 0000-0002-6943-3416
Mira Filali[5] 0000-0003-0000-7483

[1] Mining Department, Mining Engineering, National Polytechnic School, Algiers, Algeria
[2] Laboratory of Natural Resources and Management of Sensitive Environments, Department of Geology, Faculty of Earth Sciences and Architecture, Larbi Ben M'hidi University, Oum El Bouaghi, Algeria
[3] Department of Earth Sciences, Institute of Architecture and Earth Sciences, University of Farhat Abbas, Setif, Algeria
[4] Department of Earth and Universe Sciences, Laboratory of Sedimentary Environment, Mineral and Hydric Resources of Algeria Eastern, Larbi Tebessi University, Tebessa, Algeria
[5] Department of Earth Sciences, Khemis Miliana University, Algeria
✉ Corresponding author: Khaoula.bedri@g.enp.edu.dz

Summary

Fragmentation efficiency is important concerned in mining and quarrying as it effects on the productivity of different mining operations. Various parameters effect on the quality of the fragmentation. However, this research was aimed to study the effect of powder factor, burden and spacing on the blasting fragmentation in the Djebel Bouzegza C01 quarry, Boumerdes, Algeria. For the evaluation of the average size fragment, it had been used the processing image Split Desktop (P50) and compared with the results of the predictive model Kuz Ram (X50). The highest values of X50 (680.00 mm) and P50 (645.45 mm) were recorded when the largest values of (burden × spacing) that were (4.5 m × 4.5 m) and in the smallest value of the powder factor which was 0.20 kg · m^{-3}. The Fragmentation Indicator FI gives the affectedness of the Kuz Ram Model. After plotting the results on 3D surface, it has improved the results of the average size when the burden will be less than 3.70 m and the powder factor will be less than 0.64 kg · m^{-3} while to minimized the percentile of oversize fragments, it was obtained that the burden will be less than 3.70 mm, otherwise the powder factor was more than 0.30 kg · m^{-3}. Blast design parameters and the powder factor are therefore important variables in improving the results of blast fragmentation.

Keywords

design blast • powder factor • Kuz Ram model

1. Introduction

Rock fragmentation is one of the most important factors for efficient mining operations, as it minimises production costs and optimises the mining [Yilmaz 2023, Souza et al. 2018, Gharbie et al. 2009]. Blasting is the first step in reducing the size of fragments, followed by crushing and milling processes [Saadoun et al. 2022, Benyoucef et al. 2022]. The efficiency of blasting operation depends on the distribution of size fragmented rocks which directly affects mining operations such as loading, hauling, crushing and grinding [Segarra et al. 2018]. There are both controllable and uncontrollable variables that affect rock fragmentation. Controllables variables include blast design parameters and explosives properties while uncontrollable variables depend on geological structure, discontinuities, physio-mechanical properties and the presence of water [Akbari et al. 2015, Singh et al. 2015, Taib et al. 2022, 2023a, 2023b, 2024a, 2024b].

Assessment of blast results is always the concern for the mining engineers. However, analysis by processing digital image method offers a faster and more cost-effective alternative for evaluating rock fragmentation. This method involves determining the fragments size by capturing photos of the fragmented rock and analysing them using image processing software. In addition, several empirical models were developed to predict the distribution size of fragments, considering blast design parameters and rock properties. One of the most amongst model is the Kuz Ram model, which was proposed by Kuznetsov [1973] by developing Rosin and Rammler function and later it was developed by Cunningham [2005]. The Kuz Ram model was known by its simplicity, as it requires only a few input parameters such as blast design parameters and rock properties. As a result, it provides information on the mean fragment size, uniformity index and distribution of particles size [Cunningham 2005, Lawal 2021, Singh et al. 2015, Souza et al. 2018, Kerbati et al. 2020].

To improve the results of blast fragmentation, this study was carried out to investigate the influence of blast design parameters on the desired size of fragmented rock in the Djebel Bouzegza C01 quarry. For this purpose, the Kuz Ram model and the digital image processing method were used in three blast benches. By analysing the results obtained, it was evaluated the effect of blast design parameters on the degree of fragmentation blast. The findings from this study contribute to a better understanding of the controllables factors affecting blast fragmentation and can potentially provide approaches for improving blasting operations in open cast-mines and quarries.

2. Materials and methods

2.1. Analysis of fragmentation by Digital Image Processing

Split Desktop software, developed by the University of Arizona, uses digital image processing to determine the size distribution of the rock fragments. Its technique is based on the grey scale of fragmented rock, by taking digital images of the muck pile, followed by five main steps including opening the image, scaling the image, determining the image scale, using manual delineation for precision, analysing the size of the fragments size for each image, and displaying the size distribution results in of diagram form [Tavakol Elahi et al. 2017, Siddique et al. 2009, Akbari et al. 2015, Souza et al. 2018]. Digital image analysis using Split Desktop software is a valuable tool for mining engineers who need to assess the quality of blast fragmentation.

2.2. The Kuz Ram model

The Kuz-Ram model is the empirical model widely used to evaluate the distribution of blasted fragments, it has been developed to predict the average fragment size (X50) and to calculate the uniformity index (n) for the muck pile of a bench blast. The Kuz-Ram model gives a formula to determine the average size of rock fragments (X50, in cm) generated by a bench blast as follows:

$$X50 = A \cdot Q^{1/6} \cdot (115/E)^{19/30} / q^{0.8} \tag{1}$$

It considers various parameters, including the rock factor A is, the amount of TNT explosive in the blast hole Q(kg), the relative weight strength of the explosive (RWS) with respect to ANFO E (%), the RWS of the TNT is 115 and the powder factor q.

Rock factor A is generally 7 for medium hard rocks, 10 for hard, highly fissured rocks, 13 for hard, weakly fissured rock.

The formula of the uniformity index (n) is presented as follows:

$$n = (2.2 - 14B/d) \cdot (1 - W/B) \cdot [1 + (S/B - 1)/2] \cdot L/H \tag{2}$$

where:

d – the blast hole diameter (mm),
B – the burden (m),
S – the spacing (m),
W – the standard deviation of the drilling accuracy (m),
L – the charge length (m),
H – the bench height (m).

Rock factor A represents the blast ability of the rock mass and is related to the density and quality of the rock mass. It must be correctly determined to use the Kuz-Ram model. Cunningham adopted redefined the rock factor A as a function of the discontinuities, density and hardness of the rock using Lilly's blast ability index. However, several factors such as joints conditions, spacing and hardness influence factor A. This means that A' rock factor ranges from 1.7 to 21, rather than 7 to 13.

The uniformity index (n) is calculated as follows:

$$n = (2.2 - 14B/d)(1 - W/B) \sqrt{(1+S/B)/2} \cdot abs\,((Lb - Lc)/Ltot + 0.1))0.1\ (Ltot/\ H) \quad (3)$$

where:

Lb and Lc denote the bottom and column charge lengths, respectively (m),
Ltot = Lb + Lc.

Recent studies [Cardu and Calzamiglia 2021, Yilmaz 2022, Saadoun 2022, Bedri et al. 2023] have used the Kuz-Ram model for its simplicity and effectiveness in accurately predicting blast fragmentation with minimal input data. However, it is important to recognize the limitations of this model, such as the assumption of a homogeneous blast and the geological and geotechnical variations that can affect fragmentation. Despite these limitations, the Kuz-Ram model is still a valuable tool in the mining industry for evaluating fragmented rock.

3. Study area

The site chosen for this study was conducted at the Djebel Bouzegza C01 quarry, which is operated by the company of Cosider Quarries and located in Kherrouba city, in Boumerdes province; the northern of Algeria at 36°35’54” N of latitude, 3°26’25” E of longitude and between 790 m and 900 m of altitude (Fig. 1).

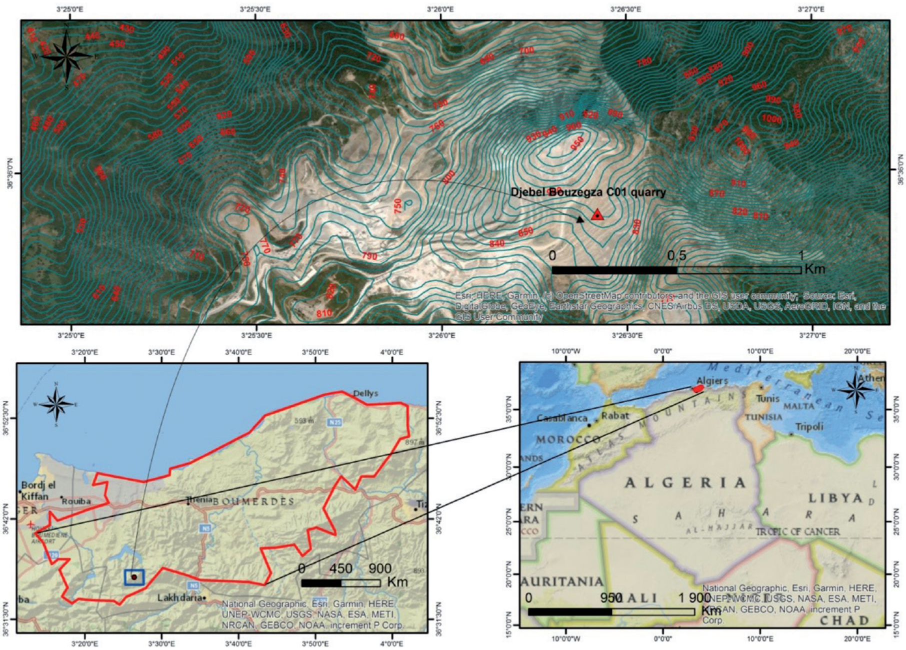

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Fig. 1. Location map of the study area

The Djebel Bouzegza C01 quarry is an important producer of aggregates (Table 1) and primarily consists of limestone deposits from the Upper Jurassic era. The limestone formations form a massive rock mass, with a summit of limestones from the Middle Eocene era [Khokha and Mors 1979]. Within this massif, various joint sets and discontinuities intersect the calcareous formations (Fig. 2).

Table 1. Physico-mechanical properties of Djebel Bouzegza C01 quarry

Density [kg/m³]	Compression strength [MPa]	Fragmentation coefficient [%] (Los Angeles)	Wear resistance [%] (Micro Deval)	Porosity
2.69	107	24	11	0.49

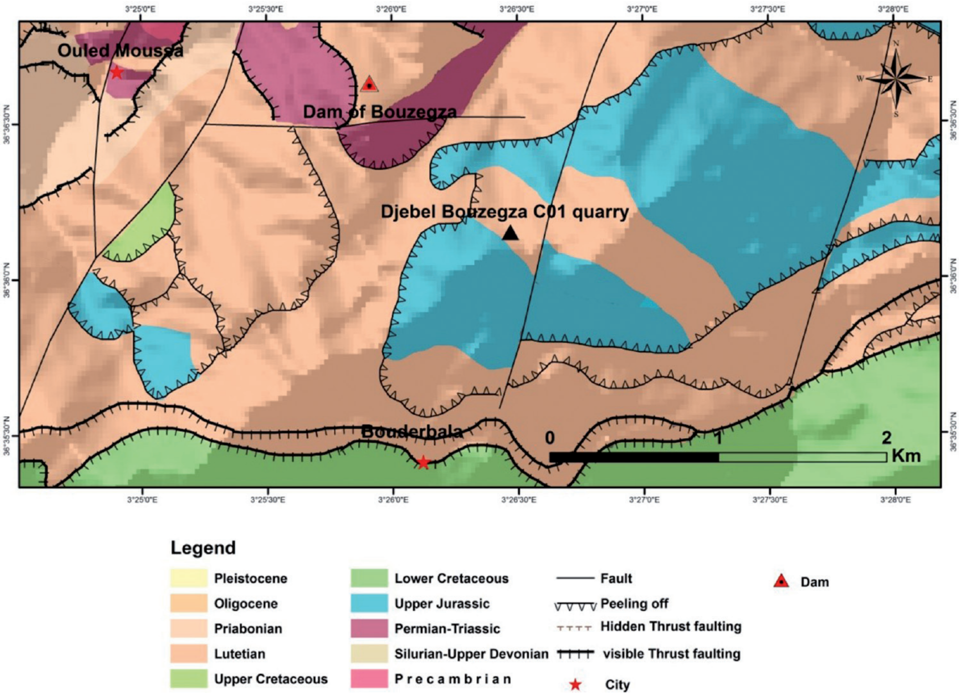

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Fig. 2. Geology of Djebel Bouzegza C01 Massif

The main family of discontinuities was characterised by a dip direction of 357°, a dip of 74° and joint spacing of 0.212 m (Fig. 3).

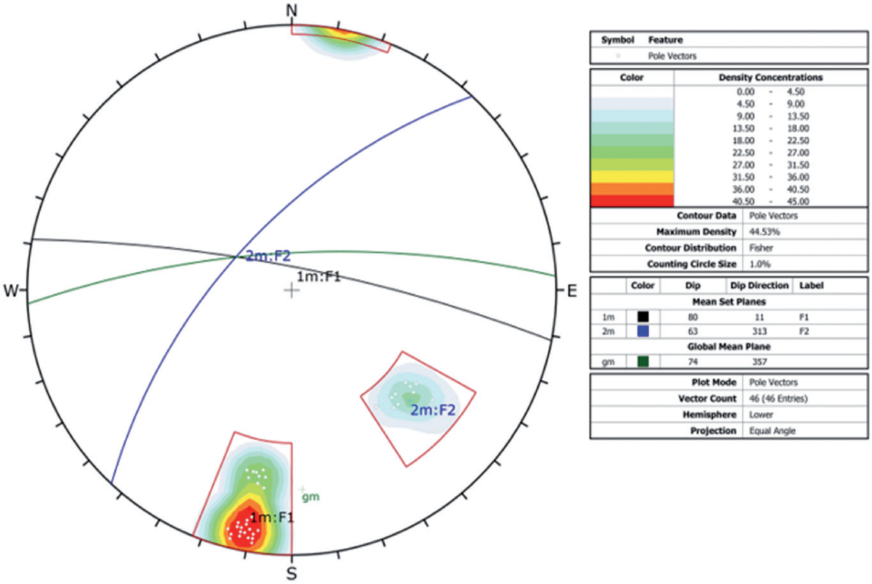

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Fig. 3. Discontinuous parameters by Dips of bench blast in the quarry of Djebel Bouzegza C01

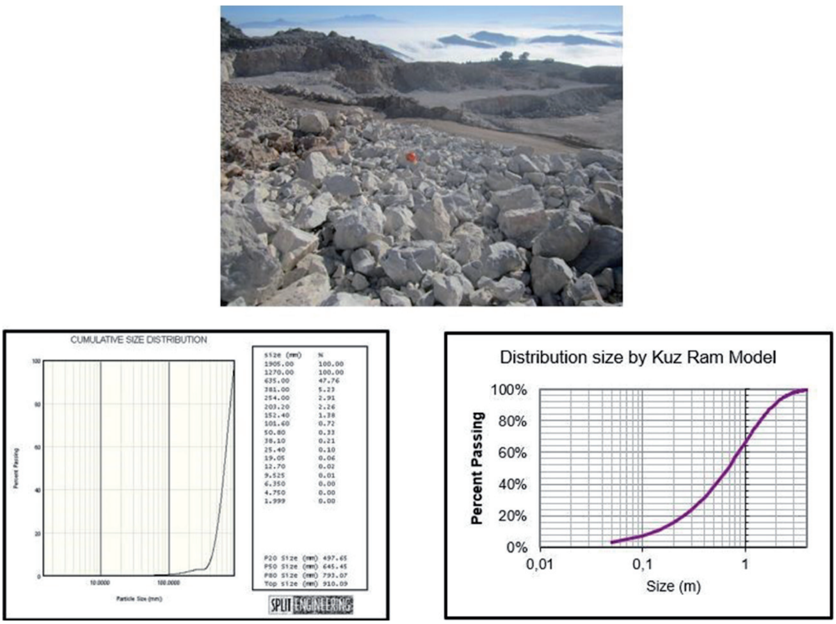

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Fig. 4. Results of distribution size of fragments in Djebel Bouzegza C01 quarry using Split Desktop and Kuz Ram model

4. Results and discussion

Blast design parameters have an effective impact on the quality of blast fragmentation. However, three blasts were conducted in Djebel Bouzegza C01 quarry to study the effect of drilling pattern and powder factor on the size of the fragmented rock. Burden and spacing are important parameters in blast design, and the ratio between burden and spacing(S/B) is 1 in this study. The main type of explosives used were Anfomil and TEMEX II. The desired size of the fragmented rock was set to a maximum of 1000 mm according to the quarry's equipment of loading, hauling, and opening of the crusher. Table 2 and Table 3 show the parameters of blast design in the five blast blocks.

The results of digital processing image using Split Desktop software P50 were compared to the results of average size X50 of the Kuz Ram model (50 means 50% of passing fragments).

It was defined the fragmentation indicator as the ratio of the average size predicted by Kuz Ram model to the average size measured by processing image software. Table 3 shows the results of P50 and X50 and the FI values for each blast.

$$FI = \frac{\text{X50 predicted}}{\text{P50 measured}} \tag{4}$$

Table 2. Parameters of blast design in Djebel Bouzegza C01 quarry

Hole diameter [mm]	Hole depth [m]	Subdrilling [m]	Stemming [m]	Charge length [m]
89	13.00	1.00	4.00	9.00

Table 3. Results of blast fragmentation X50, P50 and FI for five blasts

	Blast A	Blast B	Blast C	Blast D	Blast E
Burden B [m]	2.50	3.00	3.50	4.00	4.50
Spacing S [m]	2.50	3.00	3.50	4.00	4.50
Powder factor q [kg/m^3]	0.64	0.45	0.33	0.25	0.20
X50 of Kuz Ram [mm]	260.00	350.00	450.00	560.00	680.00
P50 of Split-Desktop [mm]	266.10	428.54	441.68	529.12	645.45
FI	0.98	0.82	1.02	1.06	1.05

It was observed in Figure 3 that Blast A had the smallest burden and spacing values (2.5 m × 2.5 m), resulting in the lowest average size of fragments with processing image by Split Desktop P50 (266.51 mm), even with the Kuz Ram model X50 (260.00 mm). Therefore, Blast E had the biggest burden and spacing values (4.5 m × 4.5 m) which resulted in the highest average size of fragments with Kuz Ram model X50 (680.00 mm) and by processing image P50 (645.45 mm).

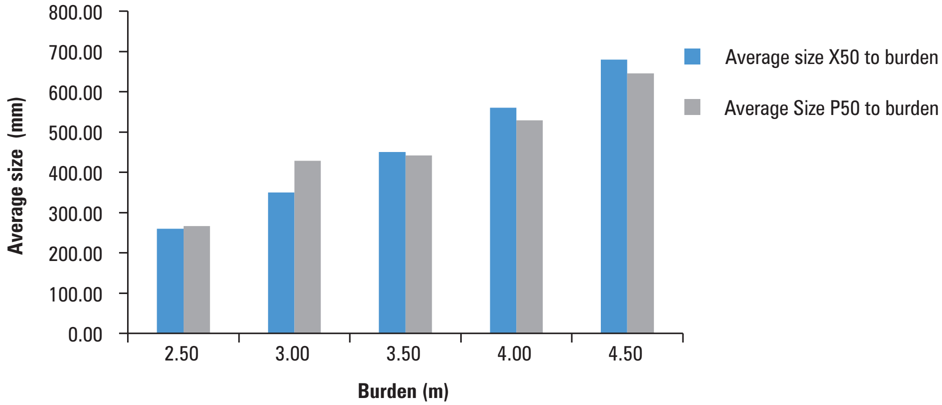

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Fig. 5. Effect of burden on the average size X50 and P50

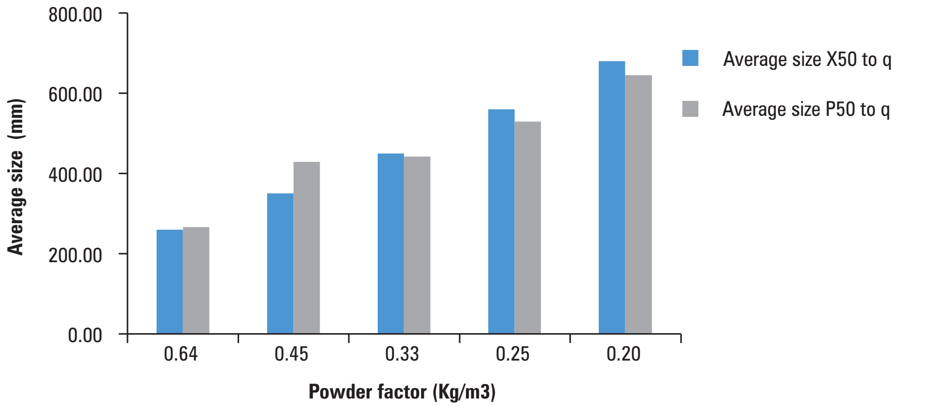

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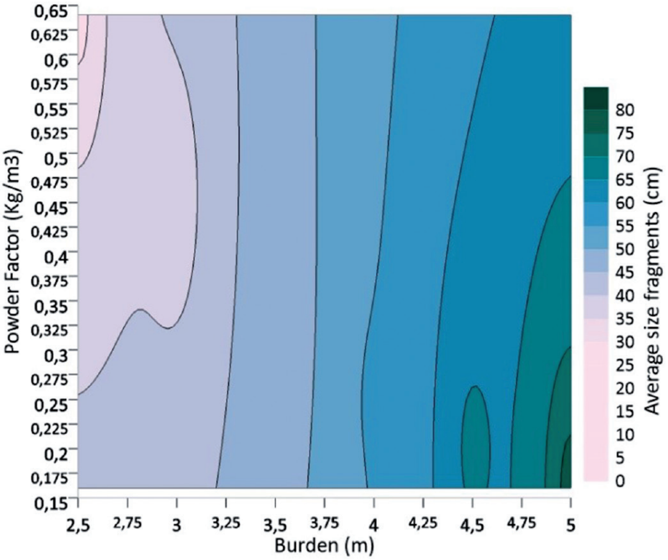
Fig. 6. Effect of powder factor on the average size X50 and P50

When the burden and spacing are small, there is less confinement for the explosive gases generated during the blasting process. This can lead to the escape of gases, which reduces the effectiveness of the blast. The escapement of explosive gases reduces the pressure and energy available for breaking the rock, leading to a less effective blast. It may result in incomplete fracturing or insufficient displacement of the rock mass. However, the larger burden and spacing can result in the formation of oversize fragments. These oversized fragments may not be desirable for certain applications and can make the blasted rock outcomes inadequate and irregular.

By analyzing the effect of powder factor on blasting rock fragmentation, Figure 6 shows that the average size of fragments by the Kuz Ram model X50 and by processing image using Split Desktop P50 increase as when the powder factor decreases. The high powder factor results in a more energetic blast and causes an excessive crushing of the mass rock, which results in a smaller and more irregular fragmentation. For a small powder factor causes more oversize fragments, as a results, the muck pile will not be with suitable size for the different mining operations.

The efficiency of blast fragmentation can be assessed by calculating the Fragmentation Indicator (FI). In this study, it was found that the values of the fragmentation indicator were between 0.82 and 1.06, it suggests that when the average size of fragments predicted by the Kuz Ram model X50 is close to the average size of fragments measured using the digital processing image P50. The fragmentation indicator results show that the Kuz Ram model was dependable and accurate. Therefore, the predictive model of Kuz Ram was used to improve the fragments size distribution, it was chosen the (burden × spacing) varied from (2.5 m × 2.5 m) to (5.0 m × 5.0 m) and the powder factor varied from 0.16 kg · m^{-3} to 0.64 kg · m^{-3}, as shown in Table 4. A surface graph can display the relationship between burden or spacing, powder factor and the results of blast fragmentation. Hence, it was plotted on 3D surface the burden or spacing and the powder factor as variables and the average size and the percentile of oversize fragments as results.

As mentioned above, the suitable size is set of 1000 mm a maximum, so the average size can be between 450 mm and 700 mm. In order to improve the results of the average size according to the parameters of blast design, when the average size is more than 450 mm and less than 600 mm, the burden will be between 3.20 m and 4.30 m, the powder factor will be less than 0.64 kg · m^{-3}, when the average size is more than 600 mm and less than 700 mm, the burden will be between 4.30 m and 4.85 m and the powder factor will be between 0.30 kg · m^{-3} and 0.64 kg · m^{-3}, as shown in Figure 7.



Source: Authors' own study

Fig. 7. The relationship between the burden, powder factor and the average size fragments

With the aim of minimizing the percentile of oversize fragments, which was set a maximum of 20%, the burden will be less than 3.70 mm and the powder factor will be less than 0.64 kg · m^{-3}, as shown in Figure 8. It was observed that the parameters were more affectedness on the quality of blast fragmentation when the burden was less than 3.70 mm, otherwise the powder factor was more than 0.30 kg · m^{-3}. To improve the results of blast fragmentation, it is necessary to play on the controllable variables such as the blast design parameters especially when the non-controllable variables are well known.

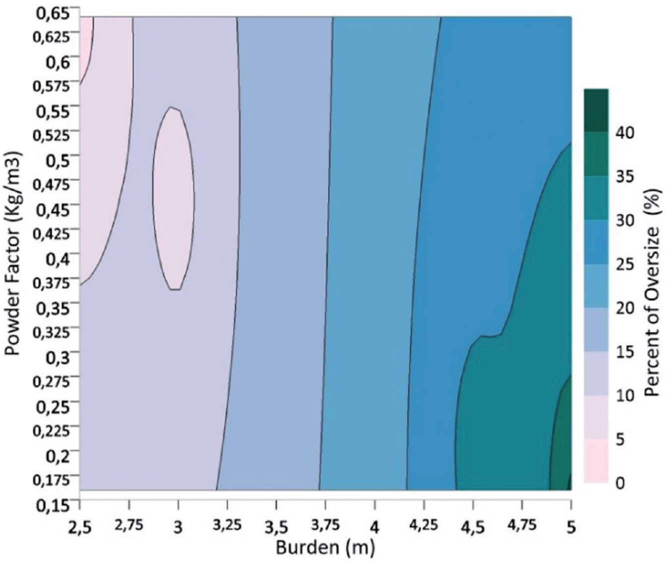


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Fig. 8. The relationship between the burden, powder factor and the percentile of oversize fragments

5. Conclusion

Various methods and techniques have been used to assess the effeteness of blasting. However, this study was conducted to evaluate the effect of powder factor and pattern drilling as burden and spacing on the results of blasting in the Djebel Bouzegza C01 limestone quarry. Using the Split Desktop processing image and the Kuz Ram model, the study found that the burden, spacing, and powder factor all had a significant effect on the size of the fragmented rock. As it was chosen the ratio between burden and spacing(E/B) to be 1, the results showed that as the burden increased, the average fragment size increase. This is because a larger burden allows for more explosive energy to be released, resulting in a larger fragments size. While the powder factor also had a significant effect on the average fragment size, as the powder factor decreases, it causes more percentile of oversize fragments, and the outcomes of blasting will not be with the desired size for the different mining operations.

For improving the results of blast fragmentation, it was defined FI fragmentation indicator as an approach between the averages size measured using the Split Desktop processing image and the other predicted by Kuz Ram model of fragments. The results show that Kuz Ram model is effectiveness in accurately predictive blast fragments. However, studying the burden, spacing and powder factor as variables, the findings of the Kuz Ram model were plotted on 3D surface to improve the average size fragment and minimize the oversize percentile were predicted.

If the characteristics geological and geotechnical are controlled in the quarry, this study can contribute to the field of blast design and fragmentation as the results can be used by mining engineers to optimize their blast designs and to achieve the desired fragmentation.

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