



Research article

Fragmentation analysis using digital image processing and empirical model (KuzRam): a comparative study

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Abstract. The rock fragmentation reflects the degree of control of blasting. Despite the accuracy of screening analysis to determine the size distribution of blasted rocks, this technique remains complex and long because of the large volume of blasted rocks. The digital image processing method can overcome these constraints of accuracy and speed. Our method uses the empirical model of KuzRam and numerical method (Digital image processing) through two image processing software's (WipFrag and Split-Desktop) to analyze the particle size distribution of rocks fragmented by explosives in Jebel Medjounes limestone quarry. The digital image processing is based on the photography of the pile of blasted rock analyzed using image processing techniques. The objective of this work is to evaluate and compare the results obtained for each blast from the two methods and to discuss the similarities and differences among them. Three different blasts with the same design were analyzed through the two methods. The result of the KuzRam model gave idealistic results due to the heterogeneity of the structure of the rocks; although, this model can be used for an initial evaluation of blast design. For better efficiency of the explosion, we proposed a new fragmentation indicator factor in order to compare the fragment produced to the estimated ideal size obtained from the KuzRam model by incorporating the blast design parameters and the rock factor. Both image processing gives close results with more accuracy for the Split-Desktop software. Our method can improve the efficiency and reduce crushing costs of the studied career.

Keywords: blasting; rock fragmentation; limestone quarry; KuzRam model; Split-Desktop; WipFrag; indicator factor

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Introduction. The surface mining process requires several fundamental operations such as drilling, blasting, loading, hauling, and crushing [1, 2]. As an initial operation, drilling and blasting have a significant impact on the performance and cost of subsequent operations [3, 4]. The role of blasting consists to achieve optimal rock fragmentation, which increases the efficiency of crushing and economizes energy [5, 6]. It must optimize the size of blasting rock to geometries which not exceed the primary crushing opening size [7].

The fragmentation of rocks by explosives depends mainly on the design of the blast and the properties of the rock mass [8, 9]. The heterogeneity degree of rocks leads to different size distributions of blasted rock piles. The control of this size distribution is very influential on the economic success of the mining operation [10-13]. Rock fragmentation by explosives must be regularly monitored, measured, analyzed, designed, planned, and accordingly modified to achieve an efficiency of the mining processes [14, 15].

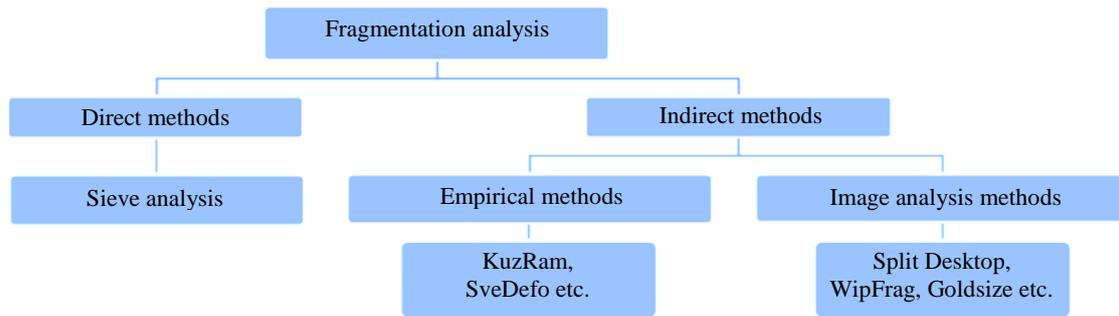


Fig.1. Flowchart of fragmentation analysis methods

The efficiency of the blast can be estimated by determining the particle size distribution of the fragments of the rock blast. There are many methods for estimating the size distribution of fragments of blasted rocks [16] including uncontrollable methods based on physical and mechanical properties of rocks and controllable methods dependent on design factors such as determination of size distribution and fragmented rocks prediction [17]. The controllable methods can be divided into direct and indirect methods, as shown in Fig.1. The direct method that is more reliable for determining the distribution of fragmented rocks is sieve analysis. Although the accuracy of this method is very high, the difficulty is mainly that it requires more time and high cost to obtain a suitable distribution of fragmented rocks. Nevertheless, the sieve analysis method can be used in part and in some low-volume experimental explosions [18, 19]. On the other hand, indirect methods including empirical and image analysis techniques provide a trade-off between the accuracy of the test and the amount of time and cost.

In some empirical models such as Larsson's equation, SveDeFo formula, KuzRam model, etc., blasting parameters are considered to determine the size distribution of blasted rock before blasting [20]. In this regard, another technique is using image processing programs which have been developed and have made rapid and accurate blast fragmentation distribution assessment possible [21, 22]. Some of these systems include IPACS, Tucips, FragScan, CIAS, GoldSize, WipFrag, Split, PowerSieve and Fragalyst [23-25]. Split-Desktop, WipFrag, FragScan and Gold Size are the most popular software packages based on 2D image processing for performing size distribution analysis of the blasted rock blocks. In image analysis method, the size distribution of fragmented rocks can be determined precisely using the captured images after blasting.

Researchers are continuously improving the models of rock fragmentation by explosives in order to compare and analyze the predicted distribution with the actual fragmentation obtained [26]. They have commonly recognized the relationship between the different levels of accuracy, speed, efficiency, and the optimization of empirical models, image analysis techniques, and numerical models [27, 28].

Due to the limitations of the results of indirect analysis methods, several researchers have conducted a number of studies related to the particle size analysis of blasted rock piles [29, 30]. Various empirical and numerical models have developed for the prediction of heap size distribution after rock blasting [31-33].

The objective of this work is to evaluate and compare the results obtained for different blast from the two methods and discuss the similarities and differences between them.

General setting. The cement company of Ain El-Kebira (SCA EK) (Setif Province) is one of the most important cement industrial units in Algeria. SCAEK is located in the northeastern of Algeria in 36°20' N latitude and 5°27' E longitude and 1040 m of Altitude. It is at 20 km northeastern of Setif city (Fig.2) [34]. One of the key success factors of this company is the use of high quality and cheap raw materials, which are available in the nearby regions [35]. This material is supplied from the Jebel

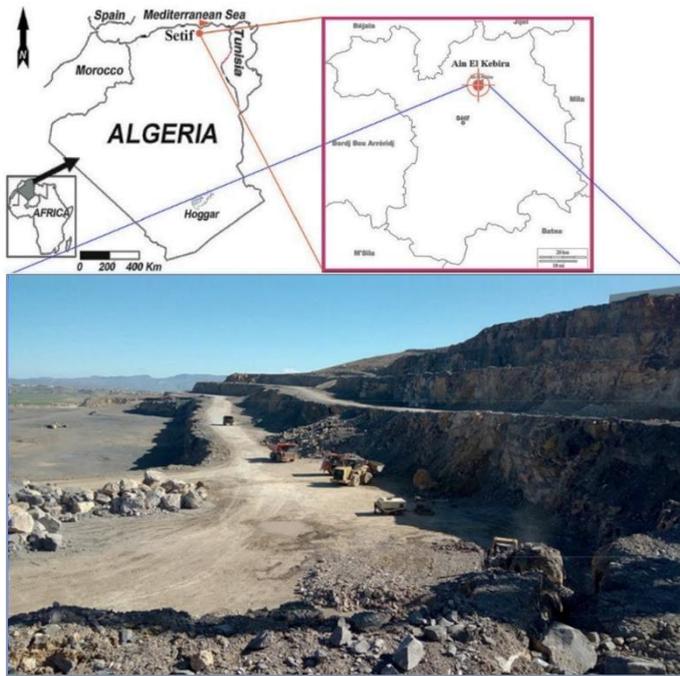


Fig.2. Jebel Medjounes limestone quarry, Ain El-Kebira, Setif

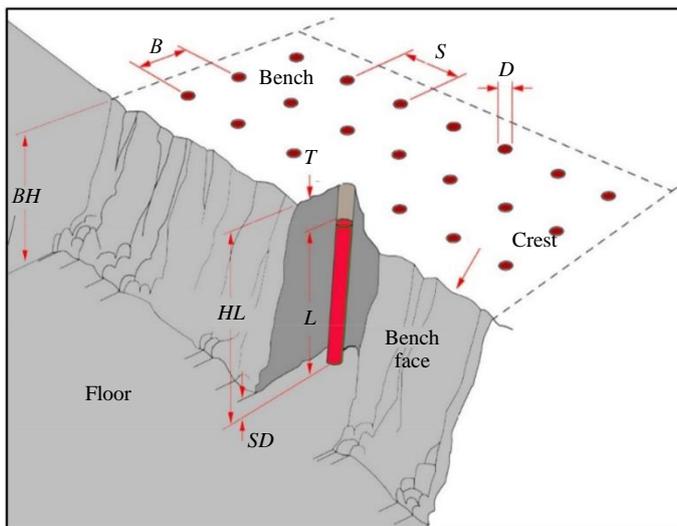


Fig.3. Blast design used in Jebel Medjounes limestone quarry

Medjounes deposit adjacent to the plant. This deposit is characterized by a very pronounced relief, extends over 15 km from east to west, with an average width of 7 km, reaching an altitude of 1461 m at the peak. The limestone rock is medium-hard, the upper part of the limestone deposit is strongly fractured, which poses problems of clogging of holes during drilling and the quality of felling, the compressive strength of the rocks is 87 MPa and a density of 2.6 t/m^3 [36].

The exploitation of the limestone quarry is carried out according to five benches, by the drilling and blasting method. The quarry operates with benches of 15 m in height and 82° of dip angle. The holes drilled with percussion with blast holes diameter of size 110 mm. Each hole is loaded with 79.15 kg of Marmanite and approximately 45 kg of ANFO per hole for a total explosive quantity in the blast hole Q equal 124.15 kg, with a charge density of explosive K . The blast holes are staggered in three rows. The blast design parameters presented in Fig.3 and the different parameters: bench height $BH - 15 \text{ m}$; burden $B - 4 \text{ m}$; spacing $S - 4 \text{ m}$; holediameter $D - 110 \text{ mm}$; subdrill - 1.65 m; stem height $T - 2.70 \text{ m}$; charge length $L - 14.1 \text{ m}$; hole length $HL - 16.8 \text{ m}$; total explosive quantity $Q - 124.15 \text{ kg}$; charge density of explosive $K - 0.48 \text{ kg/m}^3$.

Materials and methods. Blast fragmentation should continually be monitored, measured, analyzed and their designs updated. The classical methods used a sieve analysis [37]. The expensiveness of this

technique has led to the emergence of several indirect methods to estimate the size distribution [38-40].

The analysis of the particle size distribution of the fragmented rocks in the Jebel Medjounes quarry is carried out by the empirical model KuzRam and the numerical method through two image processing software's (WipFrag and Split-Desktop) as shown in Fig.4.

The KuzRam fragmentation model was derived by Cunningham (1983, 1987), from Rosin – Rammler (1933) and Kuznetsov (1973) equations to calculate the average size and the uniformity index. This model is an empirical relationship that evaluates blast fragmentation by incorporating blast design parameters, blast geometry, explosive characteristics, quantity of explosive used and rock factors [41-43]. Parameters of the KuzRam model:



- mean size fragments, m: $X_{50} = A [PF]^{-0.8} Me^{0.167} \left(\frac{115}{RWS_{ANFO}} \right)^{0.633}$;
- size distribution curve: $R(X) = 1 - e^{-\left(\frac{X}{X_c}\right)^n}$;
- uniformity index: $n = \left(2.2 - 14 \frac{B}{D} \right) \left(\frac{1 + \left(\frac{S}{B}\right)^{0.5}}{2} \right) \left(1 - \frac{E_p}{B} \right) \left(\frac{L}{BH} \right)$,

where A – rock factor; PF – specific charge in kg/m^3 ; Me – charge mass per blast holes, kg; RWS_{ANFO} – the relative weight strength of the explosive to ANFO, %; E_p – blast holes deviation.

The Split-Desktop software is a numerical image processing program, resulted from several years of research and development at the University of Arizona in the 90s. Two versions exist of this program; the first is an automatic and continuous that is used on the conveyor belt and the second is the Split-Desktop software refers to the offline, user-assisted version of the Split programs that can operate on saved images. The digital images can obtain by using a high-resolution digital camera in any support where the images are clear. Once the images are taken, they will be saved on a disk.

The WipFrag image analysis software uses an image analysis technique of fragmented rock to predict the particle size distribution in the mined rock pile. It was developed by Wipware, Inc (Canada) [40]. It processes images from various sources such as camcorders, fixed cameras, photographs, or digital files. And uses automatic algorithms to identify individual blocks and create an outline net. The images of the rock pile are acquired in the field; coupled to a scaling device to reference the size. The recorded rock pile is uploaded to the WipFrag system. The image of the broken rocks is transformed into a map or particle network, converted into volumes and weights and the results are displayed as graphs. The reliability and speed of fragment contour detection allows fully automatic remote monitoring at a rate of a few seconds per image [24].

In order to realize the size distribution of blasting operations, three blasts were carried out in different areas and with the same blasting design. The first blast was made in the upper part of the deposit wherever the massif structure is strongly fractured. The other blasts (blast 2 and blast 3) are carried out in the lower part of the deposit which has high rock quality. The data from three different blasting operations consisting of burden, hole spacing, powder factor, hole diameter, bench height, hole length, and stemming length were collected. In addition, the geomechanical properties of rocks such as UCS, density, and young's modulus were measured in the laboratory based on the International Society for Rock Mechanics (ISRM) standards.

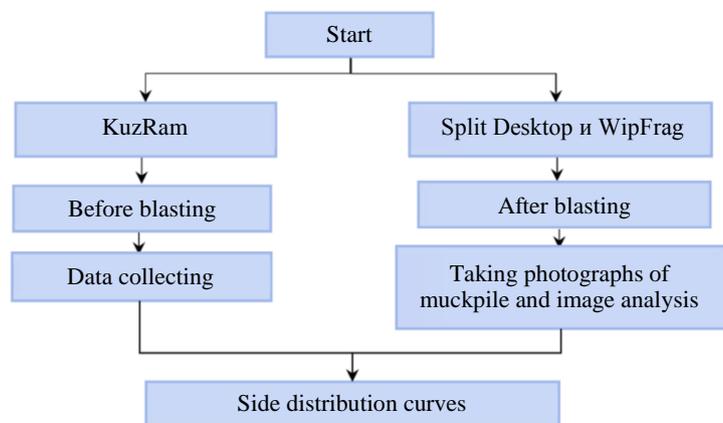


Fig.4. Fragmentation analysis steps

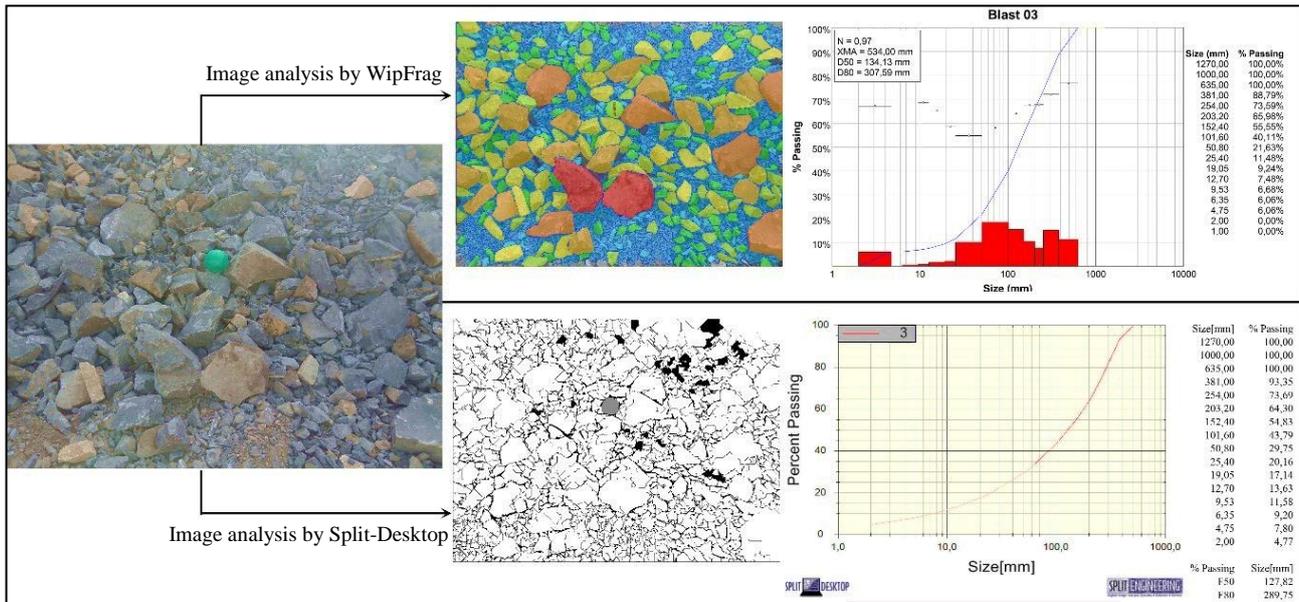


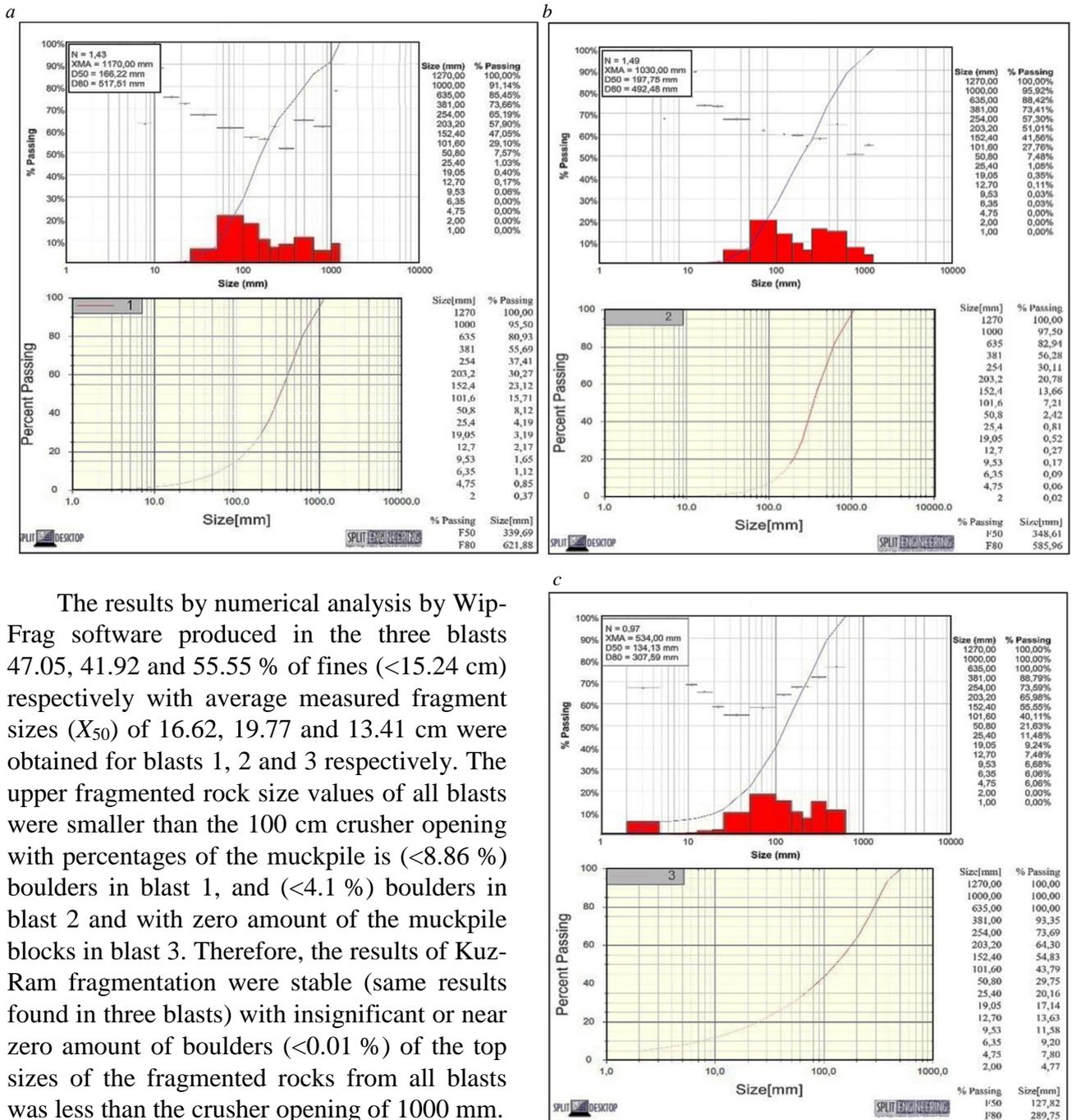
Fig.5. Main steps of image processing analysis

The parameters of the blast design were obtained and evaluated as inputs to the KuzRam model (Excel worksheet). A passing percentage of (X_{50}) was compared of the blasted rock size of 1000 mm, considering that the primary crusher installed in the quarry is accepted for fragmented rock sizes less than 1000 mm and produces a fine size product of 152.4 mm.

The image processing analysis was carried out by taking several photographs from fragmented muckpile in three steps (after blasting, in the one-third and two-thirds of loading by loader) and uploaded to the computer for WipFrag and Split-Desktop analysis. These software's uses images captured with one object (ball) that is used as scaling tool (Fig.5). These photographs were taken randomly in consideration of size variation and defined scales. In the next step, several randomly chosen photographs were selected as input file for the two-processing software. After the scaling process, in few seconds to minutes the software delineates images automatically and the status of the auto meshing displayed. After getting the mesh results, we notice that the boundaries have not been drawn correctly, and the results (particle size distribution curve) are completely different from reality, which requires every fragment so some manual editing must be done. Edge detection parameters were further manually adjusted to enhance a better result. A virtual sieve was then carried out to measure block sizes and to generate percentage passing curve of the fragment distribution and cumulative size table for each analyzed image. The processes are repeated for other images from the same muckpile, and the results are merged for better accuracy.

Results and discussion. The results of the analysis particle size distribution of the blasted rockpile obtained from the three different blasts using the Split-Desktop and WipFrag software are shown in Fig.6, while Fig.7 compare the KuzRam curve with the three results obtained from Split-Desktop and WipFrag. In the quarry of Ain El-Kebira, the maximum permissible size of the fragment that the primary crusher can handle is 100 cm.

From Fig.6 the results of blasts 1, 2, and 3 in the Split-Desktop analysis produced 23.12, 13.66, and 54.83 % fines (<15.24 cm), respectively. Average measured fragment sizes (X_{50}) of 33.96, 34.86 and 12.78 cm were obtained for blasts 1, 2 and 3 respectively. The top size of the fragmented rock from all blasts was less than the primary crusher opening of 100 cm. This implies that an insignificant amount of the muck-pile (<4.5 %) of boulders in blast 1 (Fig.6, a), (<2.5 %) of boulders in blast 2 (Fig.6, b) and with zero amount in blast 3 (Fig.6, c).



The results by numerical analysis by Wip-Frag software produced in the three blasts 47.05, 41.92 and 55.55 % of fines (<15.24 cm) respectively with average measured fragment sizes (X_{50}) of 16.62, 19.77 and 13.41 cm were obtained for blasts 1, 2 and 3 respectively. The upper fragmented rock size values of all blasts were smaller than the 100 cm crusher opening with percentages of the muckpile is (<8.86 %) boulders in blast 1, and (<4.1 %) boulders in blast 2 and with zero amount of the muckpile blocks in blast 3. Therefore, the results of Kuz-Ram fragmentation were stable (same results found in three blasts) with insignificant or near zero amount of boulders (<0.01 %) of the top sizes of the fragmented rocks from all blasts was less than the crusher opening of 1000 mm.

The Split-Desktop results show that boulders were observed in the blasts 1 and 2, with blast 3 has the least proportion of boulders of 0.00 % while blast 1 having the highest percentage boulder of 4.5 %. The maximum allowable size of the fragment that the primary crusher can handle is 1000 mm. The Split-Desktop analyses show a very closely related particle size distribution for the three blasts with X_{50} : 339.69, 348.61 and 127.82 mm respectively.

While, the particle size distribution obtained from the WipFrag program almost gives the same results as the Split-Desktop program although showing a similar trend. The WipFrag program shows that all muckpile s fragments are less than the 1000 mm benchmark; the three WipFrag analyses indicate a tolerable range of boulders, with percent passing recorded of 91.14 % in blast 1, 95.9 % in blast 2 while blast 3 has the highest percentage of passing of 100 %. The three independent WipFrag

Fig.6. Split-Desktop and WipFrag analysis of blasts: a – blast 1; b – blast 2; c – blast 3

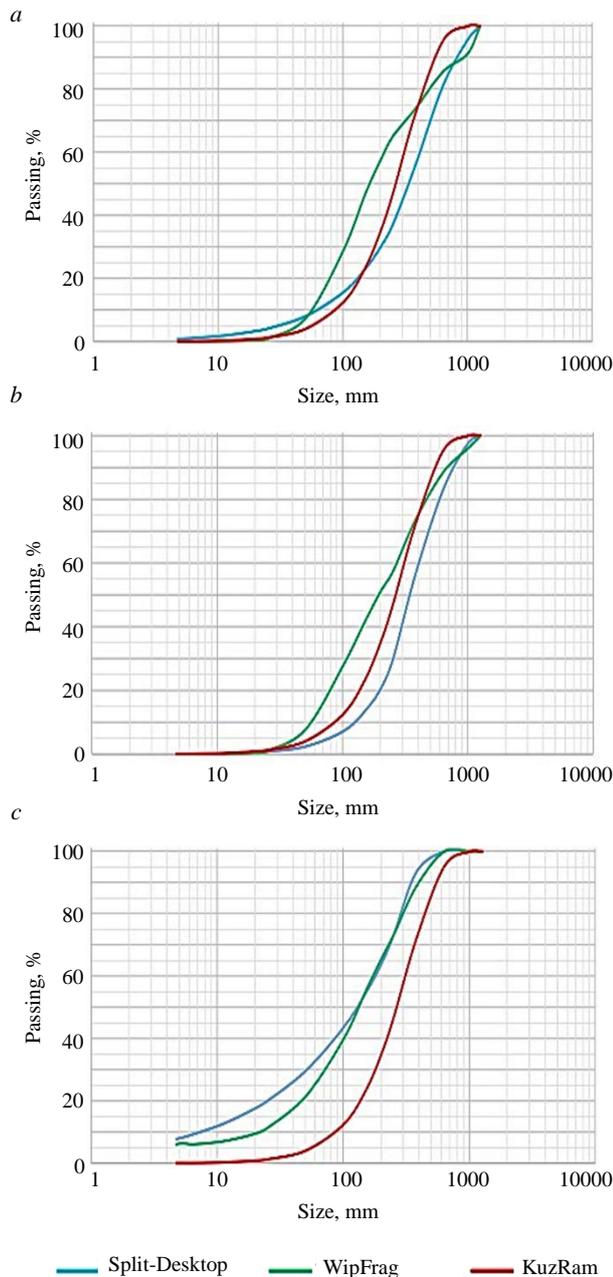


Fig.7. KuzRam compare Split-Desktop and WipFrag size distribution curves for three blasts: a – blast 1; b – blast 2; c – blast 3

mm (X_{50} size of KuzRam); X_{bm} – medium fragmented muckpile size from particle distribution analysis, mm.

The fragmentation indicator gives an idea of the fragmentation efficiency by comparing the produced fragment to the idealized size of the KuzRam model. Using the blast design parameters, explosive parameters, intact rock and joint properties, and the estimated ideal size obtained from the both Split-Desktop and WipFrag methods; through the photos processing captured in the muckpile. The FI seems to be more influenced by the rock mass structure, variable in the quarry. An FI value less than unity implies that the average fragment size obtained is larger than the ideal size while an FI that is greater than 1 shows a very efficient fragmentation with an average fragment size less than or equal to the ideal size. The value of FI would be above of 1 [45-47].

results are very similar of Split-Desktop program as shown in Fig.6, thus reflect the same implemented design. The small difference can be noticed is the variation in the structural characteristics of the rock mass [44].

According to the results of the percentage passing obtained from the three analyses shown in Table 1, the KuzRam model gives stable results in the three blasts of the order of 99.99 % of the passers-by with percentages of rate of boulders at the quarry of 0.01 %.

The analysis of the results shows a very close particle size distribution for the three blasts in both empirical and numerical methods with stable X_{50} values by the KuzRam model of 266 mm, and variable from 127.82 to 348.61 mm in the analysis by Split-Desktop software and the order of 134.13 mm to 197.75 in the numerical analysis by WipFrag software.

The percentage of boulders indicated by the numerical analysis of the muckpile confirms the results obtained with the KuzRam model but with a greater precision.

The analysis of the particle size distribution for the two image processing software's, gives a similar result of 100 % passing in the third blast. Therefore, based on the above results, and to assess the efficiency of the blasts, a new factor for the evaluation of the quality of fragmentation by blasting in the limestone quarries is introduced here as a fragmentation indicator:

$$FI = \frac{X_{KR}}{X_{bm}},$$

where X_{KR} – ideal medium size expected of the fragmented material by the KuzRam model,



Table 1

Result of percentage passing for Split -Desktop, WipFrag and KuzRam analyses

Size, mm	Passing, %						
	Split-Desktop			WipFrag			KuzRam
	Blast 1	Blast 2	Blast 3	Blast 1	Blast 2	Blast 3	
0.00	00.00	00.00	00.00	00.00	00.00	00.00	00.00
2.00	0.37	0.02	4.77	00.00	00.00	00.00	00.00
4.75	0.85	0.06	7.80	00.00	00.00	6.06	00.10
6.35	1.12	0.09	9.20	00.00	0.03	6.06	00.10
9.53	1.65	0.17	11.58	0.06	0.03	6.68	00.20
12.70	2.17	0.27	13.63	0.17	0.11	7.48	00.40
19.05	3.19	0.52	17.14	0.40	0.37	9.24	00.80
25.40	4.19	0.81	20.16	1.03	1.08	11.48	1.30
50.80	8.12	2.42	29.75	7.57	7.77	21.63	4.10
101.60	15.71	7.21	43.79	29.10	27.96	40.11	12.60
152.40	23.12	13.66	54.83	47.05	41.92	55.55	23.60
203.20	30.27	20.78	64.30	57.90	51.33	65.98	35.50
254.00	37.41	30.11	73.69	65.19	57.53	73.59	47.30
381.00	55.69	56.28	93.35	73.66	73.40	88.79	72.00
635.00	80.93	82.94	100.00	85.45	88.41	100.00	95.20
1000.00	95.50	97.50	100.00	91.14	95.90	100.00	99.90
1271.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00

In our study, based on direct observations that were made on the fragmented pile and the previous results given by the two methods (after blasting, one-third and two-thirds loading by the loader), we found that the results of the mean size fragment (X_{50}) given by the image processing technique (Split-Desktop and WipFrag) are closer to reality than that given by the KuzRam model.

According to the results obtained from the fragmentation indicator, by the image processing technique shown in Table 2, we find that:

- In WipFrag analysis, all the fragmentation indicators given by the different blasts are greater than 1 ($FI > 1$), which implies that the mean size of the fragments is less than or equal to the ideal size, which confirms that the three blasts are very efficient fragmentation, with a maximum fragmentation indicator, given by the third blast ($FI = 1.98$).
- In Split-Desktop analysis, the values of the fragmentation indicator given by blasts 1 and 2 are less than 1 ($FI = 1$), which implies that the mean size of the fragments is greater than or equal to the ideal size, which confirms that the two blasts are not efficient fragmentations, while the value of the fragmentation indicator given by the third blast is greater than 1 ($FI = 2.08$).

Table 2

Fragmentation indicators in Split-Desktop and WipFrag analysis

Blast number	X_{KR} , mm	X_{bm} , mm		FI	
		Split-Desktop	WipFrag	Split-Desktop	WipFrag
1	266	339.69	166.22	0.78	1.6
2	266	348.61	197.75	0.76	1.34
3	266	127.82	134.13	2.08	1.98

In the light of all these results, we can conclude that blast 3 records the highest values of FI (2.08 and 1.98 respectively Split-Desktop and WipFrag) and is therefore considered as the most efficient fragmentation.

Conclusion. In this paper, we use the empirical method of the KuzRam model, and the numerical method of the digital imaging software's Split-Desktop and WipFrag to study and compare the particle size distribution of the rock fragmented caused by the explosion in the limestone quarry of Ain



El-Kebira. Three different explosions of the same design are analyzed and compared. The results of the Split-Desktop analysis gave similar values, with the maximum percentage of boulders equal to 4.5 %.

The WipFrag analyses are very close to each other by maximum percentage of boulders equals 8.86 % and the minor differences can be attributed largely to the usual heterogeneity of structural features and errors caused by the miners.

However, the particle size distribution predicted by the KuzRam model clearly shows a significant change from Split-Desktop and WipFrag and cannot reflect the true value obtained (the same value on all three blasts). The KuzRam model underestimates the size of the fragments, and the average fragment size predicted is less than the correct value for the three blasts studied. These differences can be attributed to the difference in the characteristics of the discontinuities that the model assumes to be uniformly distributed in the rock mass. Since the blast design and explosives used for the three blasts are the same, it can be concluded that these differences are caused by the usual changes in the structural properties of the rock mass, such as compressive strength, crack openings, joint fillings, and groundwater conditions.

The empirical method is very useful in mining for evaluation and preliminary analysis of blast design. In this research we used a new constant called fragmentation indicator was introduced to evaluate the fragmentation efficiency of explosives. It compares the ideal average fragment size to the actual average size obtained by blasting in a relative manner.

The KuzRam model gives only idealistic results due to variation in rock structural characteristics and blast geometry, explosive properties, rock factor, and physicochemical properties of rocks not accounted for by the model affect fragmentation quality.

Empirical fragmentation models do not always give correct answers, so it is important to improve the fragmentation measurement technique according to the general conditions of the quarry being studied. The results of analysis by the digital image processing method using the two software programs are very close to each other with minor differences can be attributed largely to the different structural characteristics of the rocks formation (homogeneity, cracking, joint dip, stratification etc.) and to technical errors in the blast design. This implies the effectiveness of the image processing technique.

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