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Full length article

AN ASSESSMENT OF STEMMING TECHNIQUES AND THE PERFORMANCE OF STEMMING PLUGS IN BENCH BLASTING OPERATIONS IN PAKISTAN

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ABSTRACT

This research article presents a comparative analysis of stemming techniques and the performance of stemming plugs in bench blasting operations, based on a case study carried out in cement quarries in Pakistan. For image analysis, the Wip-Frag software is utilized in order to demonstrate the benefits of stemming plugs over traditional methods. Real-time images captured during blasting at various cement quarries reveal a substantial presence of boulders within the muck pile when using conventional stemming materials such as drill cuttings and clay. This typically requires additional time and costs for secondary drilling, blasting, or hydraulic hammering. Blast test results indicate that stemming plugs improved the throw and shape of the muck pile and significantly decreased the boulder percentage. This study also compares the results of Wip-Frag software with sieve analysis of drill cuttings, indicating potential limitations in the software's reliability for particle size distribution. These results contribute to improving blasting operations and emphasize the importance of proper stemming techniques. improving blasting efficiency, the use of stemming plugs can potentially minimize operational costs and improve overall performance.

KEYWORDS: Stemming, Wip-Frag, Blasting, Fragmentation, Sieve analysis, Explosive, Staggered

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1. INTRODUCTION

Mining is an important economic sector in any country [1]. Open cast mining, open pit mining, and underground mining methods are commonly used to extract valuable mineral resources [3]. Most economic mineral deposits are found in massive hard rocks, which need to be fragmented to extract valuable materials and separate them for further processing [4]. Rock blasting through drilling and blasting is the most common and efficient technology used in all mining operations throughout the world. [5]. Bench blasting is a critical operation in mining, playing a vital role in attaining efficient mining processes [6]. Bench blasting success depends on a number of variables, including the type and amount of explosive used, powder factor, delay system, rock geology, blast pattern, burden and angle, depth and diameter of blast holes, stemming material and length of stemming [7]. Fragmentation is a key outcome of bench blasting, as the fragmented muck pile is loaded and transported to crushers for further size reduction [8]. Stemming is also a vital feature of bench blasting, influencing the overall efficiency and effectiveness of the process [9]. Stemming material is used to confine the gases generated during the blast, facilitating efficient energy transfer to the rock mass [10]. Effective stemming leads to improved rock breakage, reduced fly rocks, reduced ground vibrations, and well-formed muck piles [11]. Conventional stemming methods usually involve a mixture of soil and drill cuttings [12]. However, dry drill cuttings have limitations in providing sufficient resistance to explosion gases, resulting in energy wastage [13]. Several engineering solutions have been proposed to improve bench blasting operations and address stemming challenges. These include the use of air plugs, stemming plugs, small inflatable balloons, plaster of Paris packing and grouting to confine explosion gases in drill hole columns [14]. In Pakistan, limestone quarries supply raw material to the cement industry, with 24 quarries discovered for this purpose [15]. Given the economic importance of bench blasting in limestone quarries, it is crucial to investigate current stemming practices and evaluate the performance of stemming materials and stemming plugs [16]. Image analysis of rock fragments and muck piles resulting from bench blasting operations can provide valuable knowledge into stemming-related challenges, best practices, and possible engineering solutions [17]. With development and advancements in computational methods, mining engineers now have access to tools that aid in solving various blasting issues encountered in surface and underground mining [18][. This study aims to investigate the current stemming practices in selected bench blasting operations, with a specific focus on analyzing the performance of the Veri-stem stemming plug in a limestone quarry. Using image analysis techniques, this study aims to identify stemming-related problems, explore suitable practices, and propose engineering solutions to optimize bench blasting operations.

2. METHODOLOGY

This study examines the effectiveness of stemming methods used in cement quarries in Pakistan's upper Punjab region. The main objectives of the study are to assess the impact of stemming material on blast outcomes, evaluate the performance of Vari-stem stemming plugs, and examine the fragmentation of blasted rock using image analysis techniques.

The data collection process was carried out in four limestone cement quarries in the upper Punjab region, focusing on blast patterns, hole dimensions, explosive quantities, stemming materials, and initiation systems. The collected data was analyzed under the following headings:

- The efficiency of Conventional Stemming Methods: This section assesses the effectiveness of traditional stemming procedures used in quarries. Evaluation of Vari-Stem Stemming Plugs Performance: The study assesses the effectiveness of Vari-stem stemming plugs as an alternative stemming method.
- Fragmentation Analysis Using Image Analysis Techniques: Fragmentation analysis was carried out utilizing image analysis techniques with WipFrag software to investigate rock fragmentation patterns.

- On-Site Observations: Muck Pile Shape, Throw, and Fly Rocks: The on-site observations related to muck pile shape, throw distance, and the occurrence of fly rocks during blasting operations was made.

WipFrag software was used to analyse pictures of the blasted muck pile, giving graphical data to accurately measure the size distribution of rock fragments. A scale reference, typically a person, was included in the images to facilitate accurate measurement of fragment sizes by the software.

To evaluate the particle size distribution of the drill cuttings, 1 kg samples of drill cuttings were collected from each quarry and subjected to sieve analysis using Tyler series sieves ranging from #4 to #65 (mesh), along with a pan sieve for all samples. In addition, pictures of the blasted muck pile were taken at each quarry site for later examination using WipFrag software to analyse rock fragmentation. The data gathered is summarized as follow:

Table 1: Blasting parameters of the selected quarries.

S. No	Blasting parameters										
	Blasting pattern	**No of holes**	**No of rows**	**Delay**	**Bench height**	**Depth of hole**	**Burdon**	**Spacing**	**Diameter of hole**	**Explosive cartridge diameter**	**Stemming material**	**Stemming length**
Quarry 1	Staggered	32	2	25 ms	6 m	7 m	3 m	3.5 m	75 mm	50 mm	Drill cuttings	1.5 m
Quarry 2	Staggered	20	2	25 ms	12 m	13 m	4.2 m	4.8 m	108 mm	75 mm	Drill cuttings	2.6 m
Quarry 3	Staggered	8	2	25 ms	12 m	13 m	4 m	5 m	115 mm	90 mm	Steaming plug	2.5 m
Quarry 4	Staggered	10	2	25 ms	4 m	5 m	4 m	5 m	115 mm	90 mm	Steaming plug	2.5 m

3. RESULTS AND DISCUSSION:

After blasting, the captured photos were analyzed using WipFrag software to assess fragmentation performance. Figure 1 shows the results from Quarry 1. In WipFrag software, a reference object is required to provide the clear understanding of the fragmented rock; therefore, a person standing at the field was taken as a reference point. The software generated a graph displaying fragment size distribution in millimeters and the corresponding percentage passing through different sizes (see Figure 2). The analysis revealed a D50 value of 516.66 mm (20.34 inches) for the median fragment size and a D80 value of 2013.97 mm (79.29 inches) for the size below which 80% of the material falls. Based on the graph, about 26.41% of the fragments were classified as boulders, which is not an optimal outcome. The majority of rock fragments, approximately 18% of the total, fell within the range of 300 mm to 400 mm.

Blast 1

Figure 1: Blasted muck file of blast 1

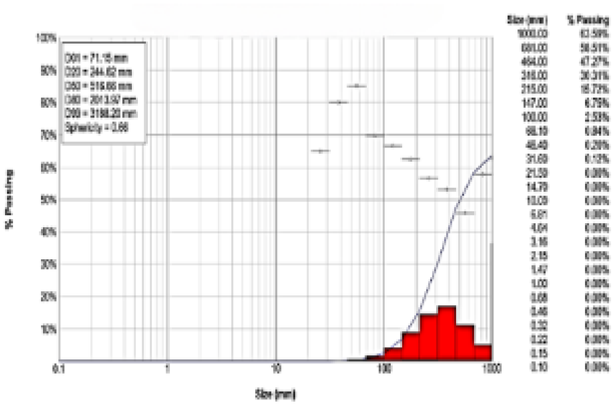

Figure 2: WipFrag result of blast 1

Blast 2

Figure 3: Blasted muck file of blast 2

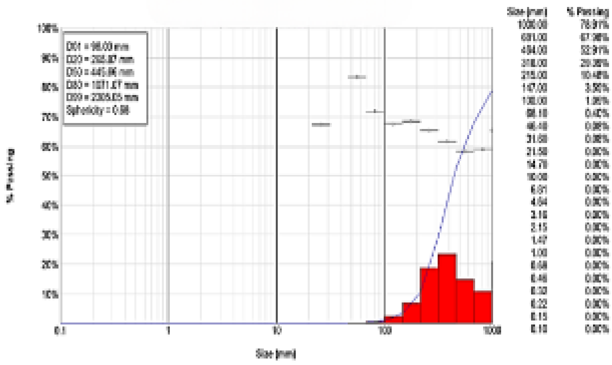

Figure 4: WipFrag analysis result of blast 2

On the basis of the photo taken after the blast, the Wip-Frag software analyzed the image (Figure 3) and generated a corresponding graph (Figure 4) showing the distribution of fragment sizes. According to the analysis, it indicates a D_{50} value of 445.66 mm for the median fragment size and a D_{80} value of 1071.07 mm, representing the size at which 80% of the fragments are smaller. About 21.09% of the fragments have been classified as boulders, while the majority of rock fragments (18% to 22% of the total) fall with in the range of 200 mm to 400 mm.

3.2 Installation of Vari-stem Stemming plug in blast no 3 and 4:

To evaluate the performance of the vari-stem stemming plug, two blast tests were conducted at Quarry 3. The stemming plugs used in the tests are shown in Figure 5.

Figure 5: Vari-stem stemming plugs

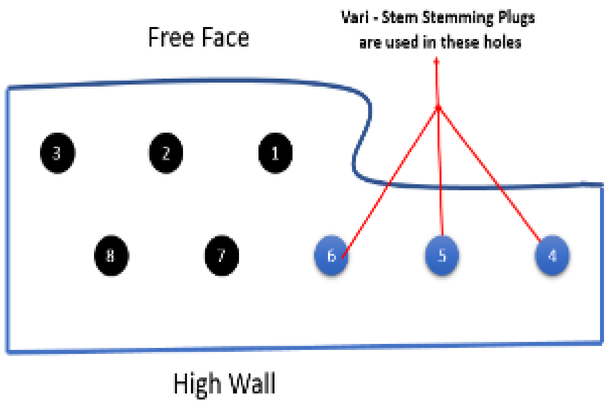

Figure 6: Blast hole pattern

Blast 3

At Bestway Cement Limited quarry, blast 1 was conducted using 8 holes with a diameter of 115 mm, drilled in a staggered pattern. In the first three holes (4, 5 and 6) stemming plugs were used, while the remaining 5 holes used the conventional stemming method without plugs. The holes with Vari-stem plugs had the plugs placed on top of the explosives, followed by a 2.5 m layer of a mixture of clay and drill cuttings. Figure 6 above displays the bench blasting design before the blast. ANFO used as the low explosive, and Wabox acted as the sensitized primer. The blast was initiated with a 25-ms delay using a shock tube (Nonel).

After the blast, Images of the blasted muck pile were captured and analyzed with the help of WipFrag software to gather fragmentation data. On-site observations included analyzing muck pile formation, material distance, breakage extent, and the presence of boulders. The below shown figure 7 illustrates the muck file.

Figure 7: Blasted muck file of blast 3

As shown in Figure 7, the Vari-Stem stemming plugs in certain holes produce finer rock fragments on that side, while larger rock fragments are observed on the side of the remaining 5 holes using mixture of drill cuttings and clay only as stemming material. Furthermore, an improvement can also be seen in the throw distance of the blasted materials of the holes with Vari-Stem stemming plugs.

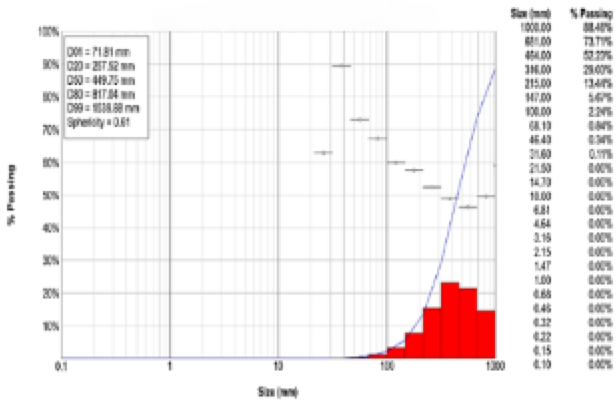

Figure 8: WipFrag analysis result of blast 3

The image of the concerned muck file is analyzed using WipFrag software to obtain digital results. The graph illustrates the size distribution of rock fragments from the blast. Only 11.54% of the rock fragments are classified as boulders, while around 40% of the rock fragmentations falls within the range of 300mm to 700mm. This blast shows a low percentage of oversized boulders. The graph also indicates that 50% of the rock fragments have a size smaller than 449.75mm, and 80% fragments have a size smaller than 817.04mm.

Blast 4

The second blast was conducted on the adjacent bench in the same cement quarry with a total of 10 holes drilled, having the hole diameter of 115mm. The objective of this blast test was to evaluate the effectiveness of two types of stemming plugs used for stemming purposes. The stemming plugs, along with a combination of drill cuttings and clay, were installed in the holes. The conventional method has been followed for explosive charging and initiation. The photo as shown in figure 9 taken after the blast illustrate the bench diagram and the placement of stemming plugs in blast holes.

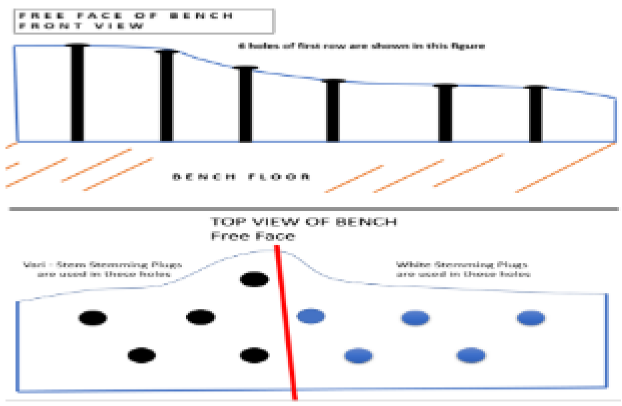

Figure 9: Blast hole pattern of blast 4

Figure 10: Blasted muck file of blast 4

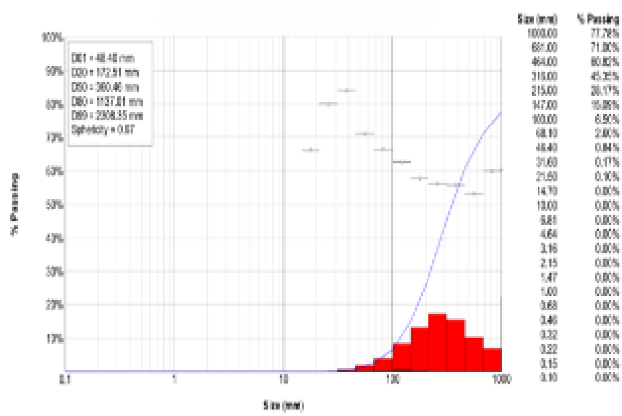

Figure 11: WipFrag analysis result of blast 4

The blast conducted on this bench resulted in unsatisfactory fragmentation (as shown in figure 10) and an increased occurrence of fly rocks, with a higher percentage of boulders. The possible reason for the outcome of this blast is the presence of plant roots in the top bench, which prevented the rock from being compacted. Consequently, cracks were present, which resulted the poor fragmentation and the occurrence of fly rocks.

Figure 11 reveals that 23% of boulders are present in the muck pile, and most of the rock fragments lie between 200 mm to 400 mm.

3. VALIDATION OF IMAGE ANALYSIS TECHNIQUE:

In order to improve work processes, researchers have adopted innovative technologies, such as image analysis technique, to evaluate rock fragmentation in the mining industry. This approach involves capturing images of the fragmented rocks and using specialized software like WipFrag to generate graphs correlating particle size with percent passing. In this study, the WipFrag software was used, a recently developed granulometry tool (Maerz et al., 1996), to measure fragmentation from digital images of blasted muck piles. To ensure accurate size calculations, an object of known length was placed on the muck file for reference. The images are then imported into WipFrag, where fragment edges are identified and manually refined through netting, providing volume and weight measurements illustrated in the graph. However, issues have been raised about presenting the full muck pile with a 2D image and the accuracy of the data acquired. To address these concerns, the drill cuttings (stemming materials) were also collected from various cement quarries and subjected to further analysis. Additionally, sieve analysis was conducted to validate the particle size distribution results from the image analysis software.

For this process, 1 kg samples of the drill cuttings were collected from four cement quarries in Punjab, Pakistan, and photographs were taken with a reference object for size reference and subjected to WipFrag. The WipFrag software was then used to generate graphical results from the photos. The sieve analysis was performed using Tyler series sieves in order to determine and validate the particle size distribution. A comparison between sieve analysis and software results was made, and variations were assessed and discussed. The findings were thoroughly investigated, revealing conclusive results.

Figure 12: Drill cuttings samples

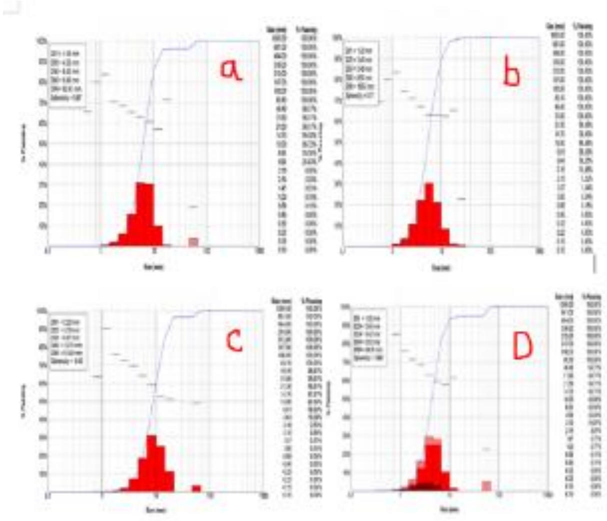

Figure 13: WipFrag analysis result of sample a, b, c, and d

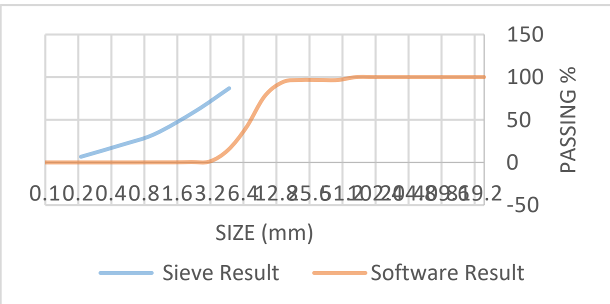

Figure 14: Comparative Size distribution analysis of sample a

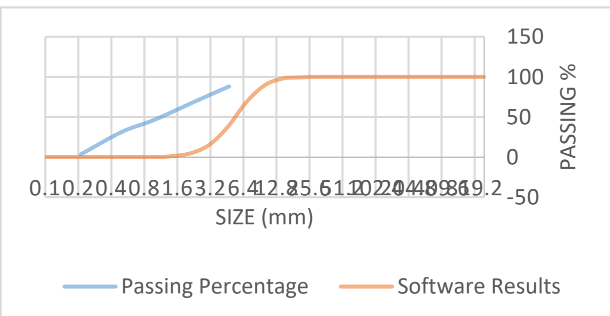

Figure 15: Comparative Size distribution analysis of sample b

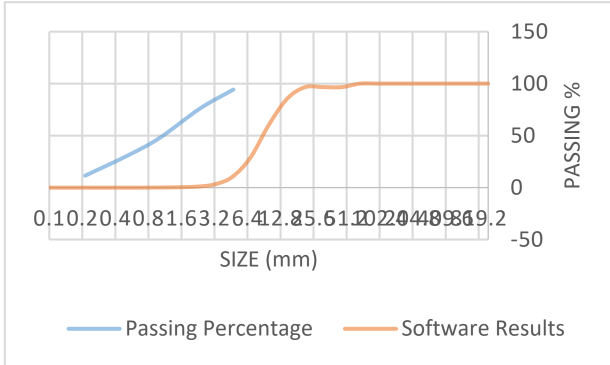

Figure 16: Comparative Size distribution analysis of sample c

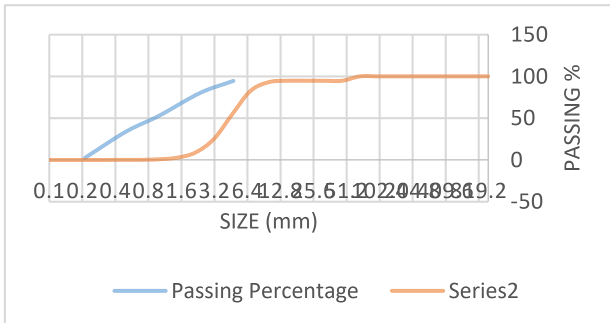

Figure 17: Comparative Size distribution analysis of sample d

The sieve analysis result showed varying percentage of drill cuttings in different size ranges. However, the WipFrag software results showed significant disparities. The WipFrag software was not able to detect sizes smaller than 0.5 mm, displays 0% in that range which is inaccurately. It also improperly indicated that only 0.19% of the drill cuttings were smaller than 1 mm in Sample 1, and 0.24% in Sample 2. Furthermore, comparing D50 results revealed differences between sieve analysis and software findings, with the graph (Figure 14) and (Figure 15) illustrating noticeable deviations in the results. Additionally, in Sample 3, the software failed to detect or measure the drill cuttings smaller than 1 mm, displaying 0% in that range, resulting in errors. The D50 comparison indicated significant deviations between sieve analysis and software results, with the graph (Figure 16) indicating differences in the outcomes. Similarly, the software results for Sample 4 deviated significantly from the sieve analysis, with only 0.77% of drill cuttings shown to be smaller than 1 mm compared to the actual value of 52.8%. in Figure 17, The D50 comparison showed more disparities, as the software indicated 50% of drill cuttings smaller than 4.4 mm, not matching the sieve analysis results of 1 mm. These findings indicate the importance of carefully considering the software's limits and possible errors when determining drill cutting sizes in quarry operations using image analysis techniques.

CONCLUSIONS

This study examined the blasting operations conducted at various cement quarries and identified typical issues, such as higher percentages of boulders, poor throw, and undesirable muck pile shapes. Consequently, additional processes like secondary drilling and blasting or hydraulic hammering were required to break up the boulders separately. As a result, downstream operations will face increased unit costs. These additional expenses further increased the entire operational budget. In comparison, experimental work involving the use of stemming plugs demonstrated significantly improved blasting outcomes compared to conventional practices. Stemming plugs resulted a lower percentage of boulders, improved the muck file throw, and shapes. These positive effects of stemming plug directly influenced downstream processes such as crushing, hauling, and loading, enhancing their efficiency and effectiveness.

Based on the findings, it is strongly recommended that quarry managers adopt the use of stemming plugs for stemming purposes. This practice has the potential to enhance blasting results by reducing boulder percentages, improving throw, and achieving desirable shapes of muck pile. These improvements can significantly impact various operational processes downstream, ultimately resulting in cost savings.

Additionally, this investigation study revealed significant concerns regarding the use and reliability of the WipFrag software for the evaluation of rock fragmentation. The software has limitations in detecting particles smaller than 0.5 mm in size and consistently provided results that were larger compared to sieve analysis measurements. Such inconsistencies undermine the software's reliability and its usefulness in determining particle size distribution. Therefore, it is advised to explore and utilize alternative techniques that can ensure precise and accurate evaluation of particle size distribution, regardless of the practice size constraint.

DECLARATIONS

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Authors' contributions:

Sami Ullah: Conceptualization, methodology, analysis and writing original draft

Muhammad Ibrahim, Roshan khan, Asif Abbas: Methodology, editing and reviewing

Tufail Ahmed: Editing and reviewing

REFERENCES

[1] Morante-Carballo, F., et al., A bibliometric analysis of the scientific research on artisanal and small-scale mining. International Journal of Environmental Research and Public Health, 2022. 19(13): p. 8156.

[2] Edwards, R., Ore deposit geology and its influence on mineral exploration. 2012: Springer Science & Business Media.

[3] Tatiya, R.R., Surface and underground excavations: methods, techniques and equipment. 2005: CRC Press.

[4] Pal Roy, P., Emerging trends in drilling and blasting technology: concerns and commitments. Arabian Journal of Geosciences, 2021. 14(7): p. 652.

[5] Bhatawdekar, R.M., et al., Review of Empirical and Intelligent Techniques for Evaluating Rock Fragmentation Induced by Blasting. Environmental Issues of Blasting: Applications of Artificial Intelligence Techniques, 2021: p. 21-39.

[6] Singh, B.K., et al., Application of digital image analysis for monitoring the behavior of factors that control the rock fragmentation in opencast bench blasting: a case study conducted over four opencast coal mines of the Talcher Coalfields, India. Journal of Sustainable Mining, 2019. 18(4): p. 247-256.

[7] Kahraman, E. and A.M. Kilic, Determination of the Effective Blasting Region by Using Fragmentation Analysis: A Field Study. Iranian Journal of Science, 2023. 47(3): p. 791-799.

[8] Zhang, Z.-X., et al., Laboratory experiment of stemming impact on rock fragmentation by a high explosive. Tunnelling and Underground Space Technology, 2020. 97: p. 103257.

[9] Tobin, G., The Importance of Energy Containment to the Blast Outcome and Justification for use of Stemming Plugs in Ove Burden Removal. 2013, Oresome Products Pty Ltd: Australia.

[10] Prasad, S., B. Choudhary, and A. Mishra. Effect of stemming to burden ratio and powder factor on blast induced rock fragmentation–a case study. in IOP conference series: materials science and engineering. 2017. IOP Publishing.

[11] Cevizci, H., A new stemming application for blasting: a case study. Rem: Revista Escola de Minas, 2013. 66: p. 513-519.

[12] Cevizci, H., Comparison of the efficiency of plaster stemming and drill cuttings stemming by numerical simulation. Journal of the Southern African Institute of Mining and Metallurgy, 2019. 119(5): p. 465-470.

[13] Ghasemi, E., Particle swarm optimization approach for forecasting backbreak induced by bench blasting. Neural Computing and Applications, 2017. 28: p. 1855-1862.

[14] Joshi, D., S. Chatterjee, and S.M. Equeenuddin, Limestone quarry production planning for consistent supply of raw materials to cement plant: A case study from Indian cement industry with a captive quarry. Journal of Mining Science, 2015. 51: p. 980-992.

[15] Oates, T.E. and W. Spiteri, Stemming and best practice in the mining industry: A literature review. Journal of the Southern African Institute of Mining and Metallurgy, 2021. 121(8): p. 415-426.

[16] Kemeny, J.M., et al., Analysis of rock fragmentation using digital image processing.

Journal of Geotechnical Engineering, 1993. 119(7): p. 1144-1160.

[17] Jahed Armaghani, D., et al., Evaluation and prediction of flyrock resulting from blasting operations using empirical and computational methods. Engineering with Computers, 2016. 32: p. 109-121.

[18] Murlidhar, B.R., D.J. Armaghani, and E.T. Mohamad, Intelligence prediction of some selected environmental issues of blasting: a review. The Open Construction & Building Technology Journal, 2020. 14(1).

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