



# Optimization of Wedge-Cut Blasting Parameters for Controlled Coal Fragmentation and Improved Development Performance in Underground Coal Mine Galleries

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## Abstract

Blasting is one of the most important operations in underground coal mine development, especially during the driving of roadways and galleries. The main objective of blasting is to fragment coal efficiently so that it can be easily loaded and transported. In underground coal mines, development galleries are usually driven within specified dimensional limits for safety and roof stability. In bord and pillar workings, development galleries are generally driven within widths ranging from 4.2 to 4.8 m depending on seam conditions and support requirements. The present case study was conducted in a gallery of 4.2 m width and 3.0 m height, which helps maintain roof stability and proper support installation.

These dimensional restrictions significantly influence the design of drilling and blasting patterns. If blasting parameters are not properly designed within these limited gallery dimensions, it may lead to oversized coal fragments, excessive fines, poor advance of the face, and damage to the roof and side walls of the gallery.

This study investigates the blasting parameters that influence coal fragmentation in underground coal mine development headings. Important parameters such as burden, spacing, hole depth, powder factor, charge distribution, and delay timing are analyzed. The study particularly examines the effectiveness of an improved wedge cut blasting pattern in rectangular development galleries.

Field observations and analysis show that proper design of wedge cut holes provides an initial free face that improves fragmentation and enhances the efficiency of subsequent blasting holes. Optimizing blasting parameters and modifying the wedge cut pattern can significantly improve advance per round, reduce fines generation, and minimize secondary blasting.



The results of this study provide guidelines for designing efficient blasting patterns for underground coal mine development under restricted gallery dimensions. Improved blast design can enhance productivity, reduce operational costs, and improve safety in underground coal mining operations.

**Keywords:** Underground coal mining, wedge cut blasting, blast design, coal fragmentation, powder factor, development blasting.

## 1. Introduction

Drilling and blasting is one of the most widely used methods for excavation in underground mining operations. In underground coal mines, blasting is important in the development of roadways, galleries, and crosscuts. Efficient blasting ensures proper fragmentation of coal, allowing easier loading, transportation, and improved productivity (Konya & Walter, 1990; Jimeno et al., 1995; Das, 2005; Jimeno et al., 1995).

In bord and pillar mining systems, galleries are developed through coal seams with limited dimensions to maintain stability and safety. Generally, the development gallery is restricted to about 3 m in height and 4.2 m in width to prevent roof instability and to facilitate proper support installation.

Because of these restricted dimensions, blast design becomes very important. The success of a blasting round largely depends on the effectiveness of the cut of blasting, which creates the first free face for the remaining holes. Common types of cut patterns include parallel cut, fan cut, and wedge cut. Among these, wedge cut is widely used in underground coal mine development due to its simplicity and effectiveness in narrow galleries.

However, improper design of wedge cut patterns may lead to poor fragmentation, low advance per round, and increased operational costs. Therefore, optimization of blasting parameters and improvement of wedge cut design are essential.

### 1.1 Objectives of the Study

The main objectives of this research are:

1. To study the blasting parameters affecting coal fragmentation in underground development headings.
2. To analyze the influence of gallery dimensions (3 m height and 4.2 m width) on blast design.
3. To examine the effectiveness of wedge cut blasting pattern in development galleries.
4. To propose improvements in the wedge cut pattern for better fragmentation and advance.
5. To suggest optimized blasting parameters for controlled fragmentation in underground coal mines.

## 2. Literature Survey

Classical blasting research established that blast performance is governed by the interaction of burden, spacing, explosive characteristics, hole geometry, and rock mass properties. The fundamental principles of blast design and fragmentation prediction have been extensively documented by Langefors and Kihlström (1978), Olofsson (1990), Konya and Walter (1990), and Jimeno et al. (1995) Das, 2005; Jimeno



et al., 1995; Holmberg et al., 2010. These studies continue to provide the theoretical basis for modern blast optimization techniques.

The design of efficient blasting patterns is essential for achieving controlled fragmentation, improved productivity, and reduced operational costs in mining operations. Previous studies have demonstrated that blast performance is strongly influenced by parameters such as burden, spacing, explosive distribution, initiation sequence, and rock mass characteristics. Gagan Tiwari et al. (2025a) emphasized that the optimization of blast design parameters plays a critical role in obtaining the desired rock fragmentation and improving overall blasting efficiency. Their findings indicated that appropriate burden and spacing combinations significantly enhance energy utilization and reduce the generation of oversized fragments.

Further research by Tiwari et al. (2025b) established a direct relationship between blast fragmentation and downstream productivity, showing that improved fragmentation positively affects loading, hauling, and crushing efficiency while reducing operational costs. These findings support the present study, where optimization of the wedge-cut blasting pattern resulted in improved fragmentation characteristics and increased advance per blast round.

The application of advanced initiation systems has also been recognized as an important factor in blast optimization. Gagan Tiwari and Chaurasia (2025) reported that electronic detonators provide superior timing accuracy compared with conventional detonators, resulting in improved burden relief, better fragmentation, and reduced blast-induced disturbances. The use of electronic delay detonators in the present case study contributed to the improved performance of the modified wedge-cut design.

Studies on vibration-safe blasting by Sahu and Chaurasia (2025a, 2025b) highlighted the importance of optimizing blast parameters and initiation sequences to control ground vibration while maintaining effective rock breakage. Their conclusions reinforce the need for systematic blast design in underground coal mine development, where excessive vibration may adversely affect roof stability and mine safety.

Risk assessment and safety considerations are equally important in underground blasting operations. Singh, Chaurasia, and Beg (2025) emphasized that well-designed blasting practices reduce operational hazards and improve safety performance in underground coal excavations. The improved wedge-cut pattern proposed in the present study contributes to safer mining operations by reducing secondary blasting requirements and improving fragmentation uniformity.

### 3. Methodology

#### 3.1 Blasting in Underground Coal Mine Development

Blasting in underground coal mines is mainly carried out during the development of roadways and galleries. The blasting operation consists of the following stages:

1. Drilling of shot holes
2. Charging of explosives
3. Stemming of holes
4. Initiation using detonators
5. Fragmentation and mucking

In underground coal mines, shot holes are usually drilled using handheld electric drills or Universal Drill Machine (UDM) with diameters around **34–38mm**.

According to classical blasting theory, burden and spacing are among the most influential design parameters affecting explosive energy distribution and fragmentation efficiency. Proper selection of these parameters improves rock breakage, reduces oversize generation, and enhances blast pull (Langefors & Kihlström, 1978; Olofsson, 1990) Roy et al. (2015). The effectiveness of blasting depends on several parameters such as:

- Burden: distance between the blast hole and the free face.
- Spacing: distance between adjacent blast holes.
- Hole depth: determines advance per blast round.
- Powder factor: amount of explosive per unit volume of coal.
- Charge distribution: arrangement of explosives within the hole.
- Delay timing: sequence and interval between detonations.

Proper design of these parameters ensures controlled fragmentation and safe blasting. According to Das (2005) and Holmberg et al. (2010), proper burden and spacing selection improves explosive energy utilization, minimizes overbreak, and enhances fragmentation efficiency in underground excavations.

### 3.2. Wedge Cut Blasting Pattern

Wedge cut blasting is one of the most commonly used methods in underground coal mine development. In this method, two or more holes are drilled at angles generally ranging from 45° to 70° toward each other to form a wedge-shaped cavity. The wedge cut creates an initial **free face**, allowing the surrounding holes to break the remaining coal effectively. Wedge cut blasting remains one of the most commonly employed cut designs in underground coal mine development because it provides an effective initial free face and requires relatively fewer drill holes compared with other cut configurations (Jimeno et al., 1995; CIMFR, n.d.)

#### Advantages of Wedge Cut

- Suitable for narrow development galleries
- Simple drilling pattern
- Provides good initial free surface
- Improves blast pull and fragmentation

However, traditional wedge cut patterns may sometimes result in incomplete breakage due to limited expansion space. The wedge cut is widely employed in underground development because it creates an initial free face that facilitates efficient breakage of the remaining rock mass. Similar observations regarding the effectiveness of cut-hole design have been reported in underground blasting studies by Jimeno et al. (1995) and Hustrulid (1999)



### **3.3. Blasting Parameters Affecting Fragmentation**

#### **3.3.1 Burden**

Burden is the distance between the blast hole and the free face. If the burden is too large, the explosive energy will not be sufficient to break the coal effectively.

#### **3.3.2 Spacing**

Spacing is the distance between adjacent blast holes. Proper spacing ensures uniform fragmentation.

#### **3.3.3 Hole Depth**

Hole depth determines the advance per blast round. In development blasting, the hole depth usually varies between **1.5 m to 2.4 m**.

#### **3.3.4 Powder Factor**

Powder factor represents the amount of explosive required to break a unit volume of coal. Proper powder factor helps achieve desired fragmentation. Powder factor is commonly used as an indicator of explosive efficiency and has a significant influence on fragmentation quality, muck pile characteristics, and overall blasting economics (Konya & Walter, 1990; Hustrulid, 1999).

#### **3.3.5 Delay Timing**

Delay detonators are used to control the sequence of blasting. Delay intervals between 25 and 75 ms are commonly employed in underground coal mine development blasting to ensure proper burden relief and progressive rock breakage. Optimized delay sequencing promotes progressive burden movement and reduces blast-induced vibration while improving fragmentation uniformity (Rai et al., 2014). Accurate delay sequencing improves burden relief and progressive breakage while reducing blast-induced vibration and improving overall blast efficiency (Holmberg et al., 2010).

### **3.4 Improvement of Wedge Cut Pattern**

To improve blasting efficiency, the conventional wedge cut pattern can be modified by adjusting hole angles, spacing, and delay timing. Proposed Improvements include:

1. Increasing the number of cut holes
2. Optimizing the angle of wedge holes
3. Providing adequate spacing between holes
4. Using electronic delay detonators with programmed firing sequences

Improved wedge cut patterns have been shown to increase face advance and improve blasting efficiency by providing better fragmentation and reducing explosive consumption.

Field studies have shown that improved cutting patterns can increase advance per blast and improve hole utilization significantly.

## 4 Case Study

### 4.1 Mine Description

A bord and pillar underground coal mine was selected for this study. Development headings were rectangular in shape with a height of 3 m and a width of 4.2 m, adopted to maintain roof stability and facilitate support installation. All blasting operations were carried out in accordance with statutory provisions and safety practices prescribed under the Coal Mines Regulations, 2017 and DGMS guidelines for underground coal mine blasting (DGMS, 2017; Ministry of Labour and Employment, 2017). The mine was extracting coal from a seam with the characteristics presented in Table 1.

**Table 1. Mine and Seam Characteristics**

Parameter	Value
Seam thickness	5 m
Gallery width	4.2 m
Gallery height	3 m
Coal compressive strength	8–12 MPa
Drill hole diameter	34 mm
Hole depth	1.8 m
Explosive used	Permitted P5 explosive
Initiation system	Electronic Delay detonators

### 4.2 Conventional Blasting Pattern

The mine initially used a conventional wedge cut blasting pattern for development blasting. The original blasting design parameters are presented in Table 2.

**Table 2. Conventional Blasting Pattern Parameters**

Parameter	Value
Number of blast holes	18
Cut holes	4
Easer holes	10
Trimmer holes	4
Hole depth	1.8 m
Burden	0.8 m
Spacing	0.6 m
Powder factor	0.55 kg/m <sup>3</sup>
Advance per round	1.2 m

The conventional blasting pattern resulted in several operational issues: large coal lumps (>500 mm), excessive fines generation, low advance per blast round, poor fragmentation requiring secondary blasting, and irregular muck pile formation. These problems reduced loading efficiency and increased development cycle time.



### 4.3 Improved Wedge Cut Blast Design

To improve the overall blasting performance and achieve better coal fragmentation, several modifications were made to the conventional wedge cut blasting design. The primary objective of these changes was to enhance the formation of the initial free face, improve explosive energy utilization, and increase the advance achieved per blasting round. The improvements included increasing the number of cut holes from four to six, which created a larger initial cavity and provided additional free faces for subsequent blast holes. The inclination angle of the cut holes was optimized to facilitate more effective coal breakage and improve blast pull. In addition, the delay sequence was refined to ensure proper burden relief and sequential fragmentation of the coal mass. The powder factor was also adjusted to achieve the desired fragmentation while maintaining efficient explosive consumption. These modifications collectively contributed to improved blasting efficiency, reduced generation of oversized fragments, and enhanced development productivity. The improved blasting parameters adopted in the study are presented in Table 3.

The increased number of cut holes generated a larger initial void, thereby improving stress relief and providing additional free faces for subsequent easer and trimmer holes. This resulted in improved utilization of explosive energy, reduced confinement, and enhanced coal fragmentation. The improved blast pull observed during field trials is attributed to the increased cavity volume and more efficient burden displacement. Furthermore, the optimized hole inclination and improved delay sequencing facilitated progressive coal breakage and better burden relief, resulting in a more uniform fragment size distribution and improved muck pile characteristics.

**Table 3. Improved Wedge Cut Blasting Design Parameters**

Parameter	Improved Design
Total blast holes	20
Cut holes	6
Easer holes	10
Trimmer holes	4
Hole depth	1.8 m
Burden	0.8 m
Spacing	1.0 m
Rock-to-Explosive Ratio (RER)	1.7 Tonne/kg
Delay sequence	0–60 ms
Explosive per hole	0.694 kg
Total explosive	13.875 kg
Powder factor	0.69 kg/m <sup>3</sup>

### 4.4 Powder Factor Calculations:

#### Final Wedge Cut Blast Design and Powder Factor Calculation

The following calculations confirm the improved blast design parameters for a gallery of 4.2 m (W) × 3 m (H) with a hole depth of 1.8 m and an advance per round of 1.6 m.

**Volume of Rock Blasted per Round:**

$$\text{Volume} = \text{Height} \times \text{Width} \times \text{Advance} = 3 \times 4.2 \times 1.6 = 20.16 \text{ m}^3$$

**Considering specific gravity of coal ( $\rho = 1.2 \text{ t/m}^3$ ):**

$$\text{Adjusted Volume} = 20.16 \times 1.2 = 24.192 \text{ tonne}$$

**Total Explosive Consumed:**

$$\text{Total explosive} = 20 \text{ holes} \times 0.694 \text{ kg/hole} = 13.88 \text{ kg}$$

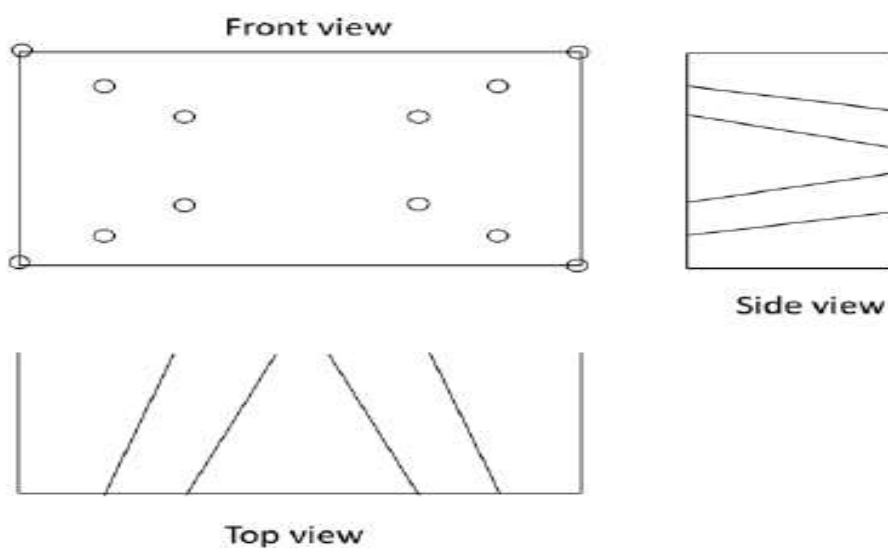
**Powder Factor (PF):**

$$\text{PF} = \text{Explosive} / \text{Volume}$$

$$13.875 / 20.16 = 0.69 \text{ kg/m}^3$$

**Rock-to-explosive ratio**

$$\text{RER} = \frac{24.19}{13.875} = 1.74 \text{ tonne/kg}$$

**Fig. 1 Front View, Top View & Side View**

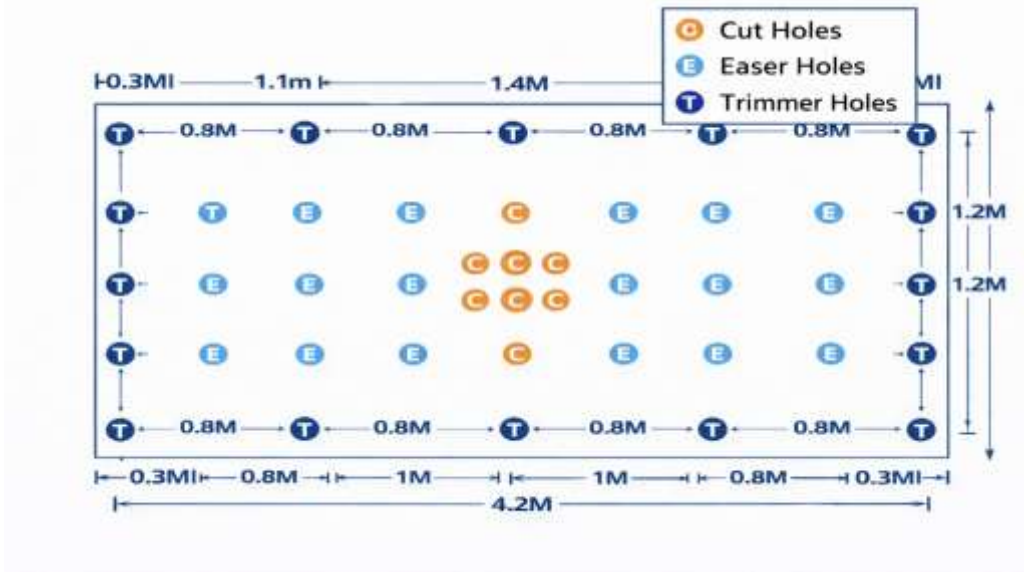


Fig.2 Wedge cut pattern

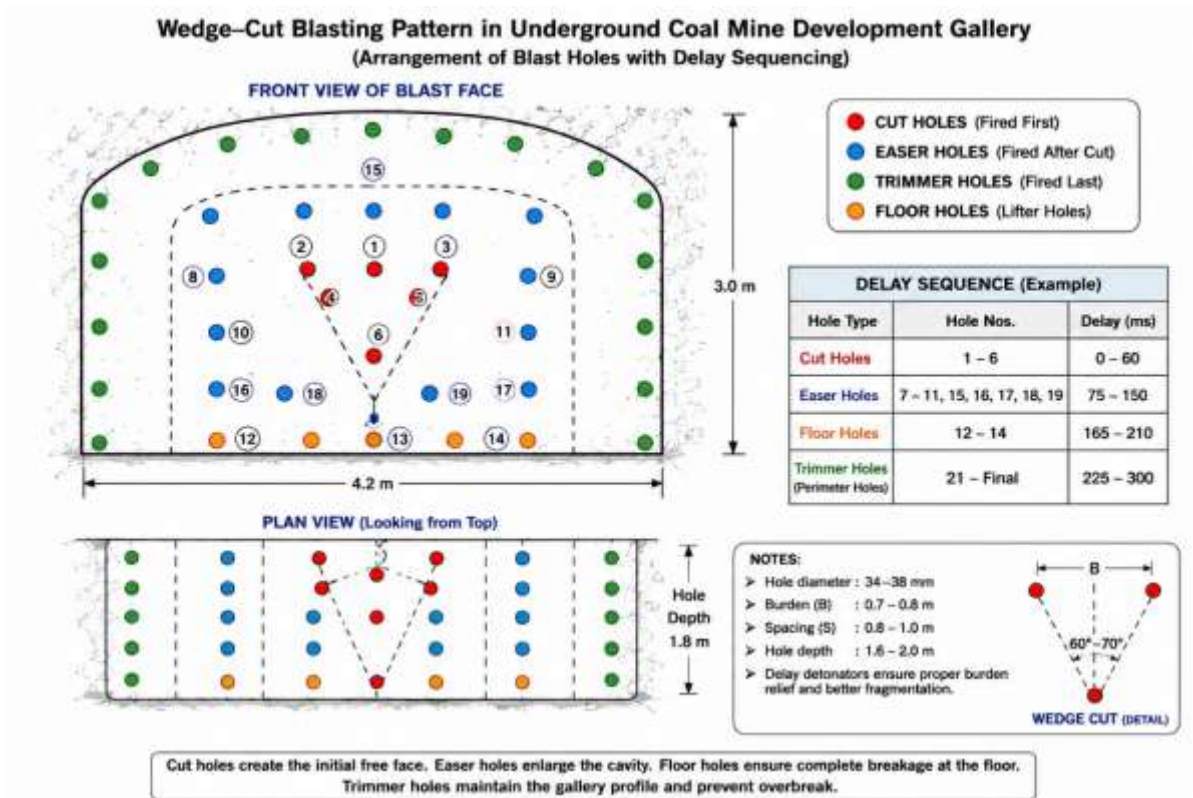


Fig. 3 Typical wedge-cut blasting pattern showing the arrangement of cut holes, easer holes, trimmer holes, and floor holes with delay sequencing in an underground coal mine development gallery.

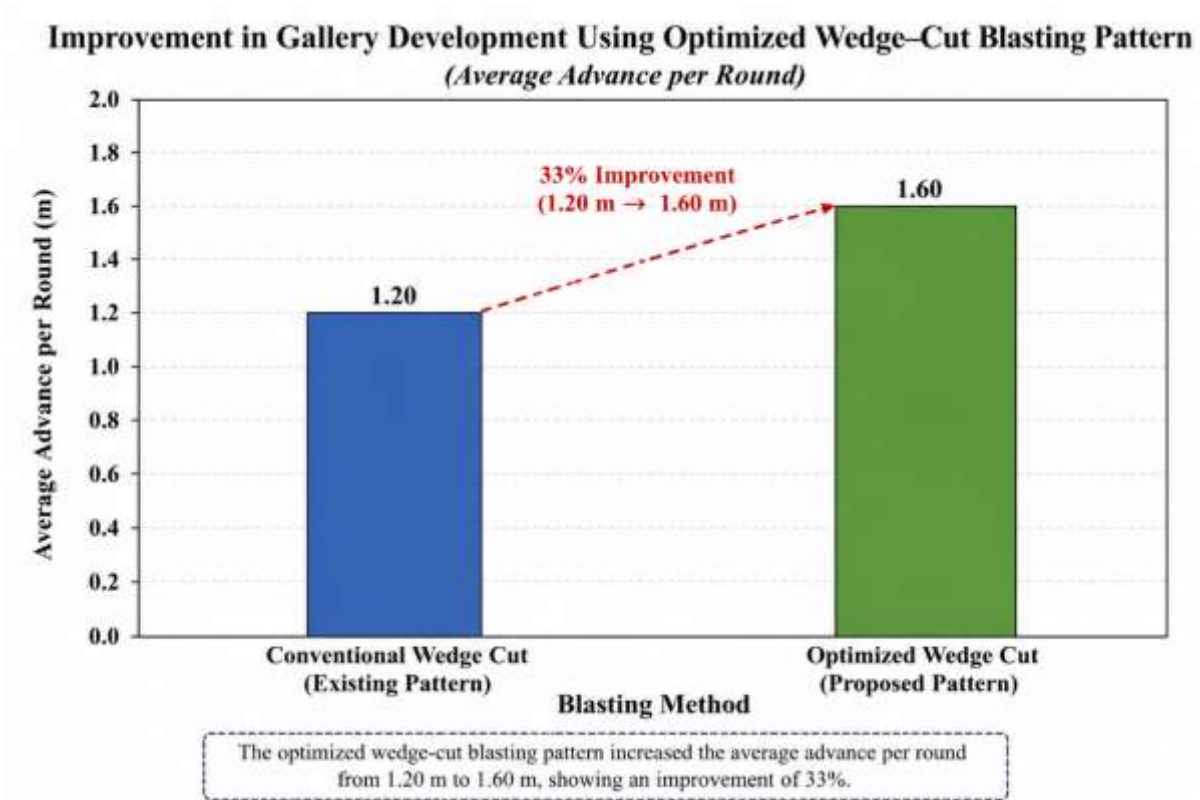
## 5. Results and Discussion

After implementing the improved wedge cut pattern, blasting performance was evaluated over 20 blasting rounds. A comparative summary of conventional versus improved patterns is presented in Table 4.

**Table 4. Performance Comparison**

Parameter	Conventional Pattern	Improved Pattern
Average advance per round	1.2 m	1.6 m
Oversized fragments	28 %	12 %
Fines generation	20 %	14 %
Secondary blasting	Frequent	Rare
Yield per round	18.14 tonne	24.19 tonne

The optimized wedge cut pattern improved advance per round by 33% and increased coal yield per round by 33%.



**Fig.4 Graph indicating the improvement of pull per round during advancing**

### 5.1 Fragmentation Analysis

Fragmentation analysis showed that the improved wedge cut pattern produced **more uniform coal fragments**.

**Table 5. Fragmentation Size Distribution Comparison**

Fragment Size	Conventional (%)	Improved (%)
>500 mm	28	12
200–500 mm	42	50
<200 mm	30	38

The reduction in oversized fragments improved loading efficiency and reduced secondary blasting operations.

## 5.2 Discussion

The case study results indicate that proper design of wedge cut holes is critical for effective development blasting. Increasing the number of cut holes from 4 to 6 created a larger initial cavity, which allowed the explosive energy from surrounding holes to break coal more efficiently, producing a more uniform fragment size distribution.

The improved blasting parameters resulted in better fragmentation, increased advance per round, reduced secondary blasting, improved loading efficiency, and reduced development cycle time. Since underground coal mine galleries have restricted dimensions (3 m height and 4.2 m width), optimizing blasting parameters becomes essential for effective and safe development operations. The observed improvements are consistent with established blasting theories, which indicate that enhanced free-face creation and improved burden relief increase explosive energy utilization and fragmentation efficiency (Olofsson, 1990; Hustrulid, 1999). Similar relationships between blast design optimization and fragmentation quality have also been reported by Singh et al. (2016).

The improvement achieved in the present study is consistent with previous findings that emphasize the importance of optimized cut-hole geometry and initiation sequencing in underground coal mine development blasting (Roy et al., 2015; Das, 2005). The larger cavity generated by the modified wedge cut improved burden relief and enabled more effective utilization of explosive energy.

The 33% increase in advance per round (from 1.2 m to 1.6 m) translates directly into improved roadway development rates, with significant positive implications for mine productivity and cost efficiency.

## 5.3 Practical Implications

The findings of this case study provide practical guidelines for underground coal mine development:

1. Proper wedge cut design improves overall blasting efficiency and reduces operational delays.
2. Increasing the number of cut holes improves initial free face formation and cavity size.
3. Optimizing burden and spacing reduces oversized fragments and improves mucking efficiency.
4. Controlled powder factor achieves desired fragmentation while minimizing explosive waste.
5. Improved blast design reduces development cycle time, improving overall mine productivity.

## 6. Conclusion

This study demonstrates that improving the wedge cut blasting pattern significantly enhances fragmentation and development efficiency in underground coal mines. For rectangular development galleries with dimensions of 3 m height and 4.2 m width, optimized blast design ensures better energy utilization and improved operational productivity.

The improved wedge cut pattern increased advance per round by 33% (from 1.2 m to 1.6 m), reduced oversized fragments from 28% to 12%, and minimized secondary blasting operations. These results confirm that careful design of blasting parameters—particularly wedge cut hole number, angle, burden, spacing, and delay sequence—is essential for achieving controlled fragmentation and efficient underground coal mine development within restricted gallery dimensions.



Future work should investigate the application of numerical simulation tools for blast pattern optimization and evaluate the performance of alternative initiation systems under varying coal seam conditions.

## Reference

1. Central Institute of Mining and Fuel Research. (n.d.). *Research reports on development blasting and wedge cut blasting patterns in underground coal mines*. CIMFR.
2. Das, S. K. (2005). *Engineering rock blasting operations*. Oxford & IBH Publishing Co.
3. Directorate General of Mines Safety. (2017). *Guidelines and safety practices for blasting in underground coal mines*. Government of India.
4. Holmberg, R., Persson, P. A., & Lee, J. (2010). *Rock blasting and explosives engineering*. CRC Press.
5. Hustrulid, W. (1999). *Blasting Principles for Open Pit Mining*. CRC Press.
6. Jimeno, C. L., Jimeno, E. L., & Ayala, F. J. (1995). *Drilling and blasting of rocks*. A. A. Balkema.
7. Jimeno, C. L., Jimeno, E. L., & Carcedo, F. J. A. (1995). *Drilling and Blasting of Rocks*. CRC Press.
8. Konya, C. J., & Walter, E. J. (1990). *Surface Blast Design*. Prentice Hall.
9. Laku, L. C., Soni, H. P., & Singh, R. D. (n.d.). *Mining engineering*.
10. Langefors, U., & Kihlström, B. (1978). *The Modern Technique of Rock Blasting*. Wiley-Interscience.
11. Ministry of Labour and Employment. (2017). *Coal Mines Regulations, 2017*. Government of India.
12. Olofsson, S. O. (1990). *Applied Explosives Technology for Construction and Mining*. Applex.
13. Rai, P., Singh, T. N., & Singh, V. K. (2014). Assessment of blast-induced ground vibration and optimization of blasting parameters. *International Journal of Mining Science and Technology*, 24(5), 663–669.
14. Raidas, J., & Chaurasia, R. C. (2025). *Study of Blast Fragmentation and Shovel Efficiency in a Surface Coal Mine*. *International Journal for Research in Applied Science & Engineering Technology*, 13(9).
15. Roy, M. P., Singh, P. K., & Sarim, M. D. (2015). Optimization of blasting parameters in underground coal mines. *Journal of Rock Mechanics and Geotechnical Engineering*.
16. Sahu, R. K., & Chaurasia, R. C. (2025). *Reducing Seismic Disturbances through Blasting Design Strategies*. *International Research Journal of Modernization in Engineering, Technology and Science*, 7(7).
17. Sahu, R. K., & Chaurasia, R. C. (2025). *Vibration-Safe Blasting: A Study on Parameter Optimization—A Meta-Analytic Review*. *International Journal of Engineering & Science Research*, 15(2), 749–761.
18. Singh, G., Chaurasia, R. C., & Beg, I. A. (2025). *Risk Assessment and Safety Management in Underground Coal Excavation: A Case Study Analysis*. *International Journal on Science and Technology*, 16(3).
19. Singh, G., Singh, S. K., Chaurasia, R. C., & Jain, A. K. (2024). *The Present and Future Prospect of Artificial Intelligence in the Mining Industry*. *Industrial Engineering Journal*, 53(4).
20. Singh, P. K., Roy, M. P., Paswan, R. K., Sarim, M. D., Kumar, S., & Jha, R. R. (2016). Rock fragmentation control in opencast blasting. *Journal of Rock Mechanics and Geotechnical Engineering*, 8(2), 225–237.
21. Tiwari, G., & Chaurasia, R. C. (2025). *Various Factors which are Responsible for the Use of Electronic Detonators in Underground Coal Mines*. *International Journal for Multidisciplinary Research*, 7(5).
22. Tiwari, G., Chaurasia, R. C., Bisen, V., Daharwal, V., Kiran, A. V., & Singh, K. (2025). *Blast Design for Obtaining Desired Rock Fragmentation*. *Journal of Civil and Environmental Engineering*, 13(7), 227–240.
23. Tiwari, G., Chaurasia, R. C., Bisen, V., Daharwal, V., Kiran, A. V., & Singh, K. (2025). *Linking Blast Fragmentation to Energy Efficiency and Downstream Productivity in Opencast Mining*. *Journal of Civil and Environmental Engineering*, 13(9), 203–209.



24. Tripathi, S. K., & Chaurasia, R. C. (2025). *Exploring Peak Productivity Achievable with Continuous Miners*. International Journal of Innovative Research in Technology, 12(3).
25. Tripathi, S. K., & Chaurasia, R. C. (2025). *Investigation Into Optimum Production By Continuous Miner*. IRJMETS, 7(4).
26. Yadav, I., & Chaurasia, R. C. (2025). *A Comprehensive Review of Coal Mining: Techniques, Environmental Impacts, Health and Safety Issues, and Sustainable Future Prospects*. International Journal of Sciences and Innovation Engineering, 2(12), 1186–1197.
27. Yadav, I., & Chaurasia, R. C. (2025). *Coal Mining: Techniques, Impacts, and Future Prospects*. IJFMR, 7(4).