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Research Paper

Enhancing Blasting Efficiency and Environmental Performance through Chamber Blasting in Opencast Mining

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ABSTRACT

Opencast mining depends heavily on blasting for rock fragmentation and excavation. Conventional blasting methods often result in suboptimal fragmentation, high ground vibration, excessive explosive consumption, and substantial environmental impacts such as air overpressure, noise, and flyrock. Chamber blasting, an advanced controlled blasting technique involving controlled initiation within partially confined cavities (chambers), presents a promising alternative for improving blasting efficiency while minimising ecological disruption. This research explores principles of chamber blasting, design methodology, performance evaluation, and its environmental advantages in opencast contexts. Comparative analysis with conventional blasting demonstrates that chamber blasting enhances fragmentation, reduces explosive usage, mitigates vibration and noise pollution, and improves operational economics. The study concludes that chamber blasting can be an effective, sustainable blasting strategy for modern opencast mining operations.

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1. INTRODUCTION

Blasting is central to opencast mining operations, accounting for a significant portion of rock breakage activities. Traditional full-column explosive charging within blast holes often results in uneven energy distribution, oversized fragments, and environmental issues such as ground vibration, airblast overpressure, and excessive noise. These concerns have increased regulatory scrutiny and operational challenges globally. Chamber blasting is an advanced controlled blasting technique that adapts principles of partial confinement, delayed initiation patterns, and altered charge distribution to improve

explosive energy utilisation. Instead of charging blast holes in a continuous explosive column, chamber blasting employs strategic cavity development (chambers) and controlled initiation sequences to optimise shock wave propagation and gas expansion. The primary aim of this research is to investigate the effectiveness of chamber blasting in enhancing fragmentation, minimising negative environmental impacts, and improving operational performance in opencast mining.

2. LITERATURE REVIEW

Controlled blasting techniques—such as pre-splitting, cushion blasting, air decking, and decoupling—have been widely studied for minimising environmental impact and improving fragmentation. Conventional practices often emphasise reduced explosive charge and adjusted burden spacing to achieve desired outcomes. However, most studies indicate that uncontrolled energy release remains a challenge in large-scale opencast operations.

Chamber blasting, traditionally applied in underground mining to control blast propagation and support structures, has received limited research attention in surface mining. Its potential for controlled energy distribution and interaction with rock mass suggests significant possibilities for opencast applications.

3. Principles of Chamber Blasting

Chamber blasting involves three key components:

1. **Partial Confinement:** Creating a cavity (chamber) at the bottom portion of drill holes to localise explosive energy and modify stress wave behaviour within the rock mass.
2. **Controlled Initiation Sequencing:** Using delayed detonators and timing strategies to direct energy flow and reduce cumulative ground vibration.
3. **Energy Redistribution:** Altering conventional explosive charge profiles to enhance crack propagation and reduce non-productive energy loss.

The chamber functions as a temporary detonation cavity that reflects stress waves and intensifies tensile waves that promote crack initiation. This reduces the overall requirement for explosive charge and improves fragmentation outcomes.

4. METHODOLOGY

4.1 Study Design

This research uses a mixed-method approach that includes:

- Analytical modelling of pressure wave interactions in chambered versus conventional blasts.
- Simulation studies using numerical methods (Finite Element Method and Discrete Element Method) to assess stress wave propagation, fracture network distribution, and resultant fragment sizes.
- Case study comparisons based on field blast records from a medium-hard rock opencast quarry.

4.2 Performance Indicators

Key performance indices include:

- **Fragmentation Quality:** Average fragment size (using sieve analysis and image processing methods).
- **Explosive Consumption:** Specific charge (kg/m^3 of rock).
- **Ground Vibration:** Peak Particle Velocity (PPV) levels measured using field seismographs.
- **Environmental Impact Metrics:** Noise levels (dB), air overpressure, and dust emissions.

5. Analytical Framework

5.1 Stress Wave Behaviour around Chambers

When explosive detonation occurs within a chamber:

- The presence of an air-filled cavity induces reflections of compressive waves as tensile waves due to impedance mismatch.
- Tensile waves are more effective in rock fracturing, resulting in greater crack propagation.
- Controlled release of gas pressure further enhances material breakage while suppressing high-frequency shock components associated with environmental disturbances.

The reflection coefficient R at the explosive-cavity interface is mathematically expressed as:

$$R = \frac{Z_{\text{medium}} - Z_{\text{cavity}}}{Z_{\text{medium}} + Z_{\text{cavity}}}$$

Where:

- Z_{medium} = Impedance of rock mass
- Z_{cavity} = Impedance of the chamber (air)

Since air impedance is negligible, the reflection coefficient approaches unity, resulting in significant tensile wave energy within the chamber.

6. RESULTS

6.1 Fragmentation Outcomes

Comparative simulation and field data indicate that chamber blasting reduces mean fragment size by **10–20%** relative to conventional blasting. Image analysis shows a narrower particle size distribution, facilitating better loading and crusher throughput.

6.2 Explosive Usage Efficiency

Specific explosive consumption decreased by **12–22%** across multiple test scenarios. Improved energy utilisation within the chamber contributes to these savings.

6.3 Ground Vibration and Noise Reduction

Empirical vibration monitoring revealed that chamber blasting consistently produced lower Peak Particle Velocity (PPV) levels. Average PPV reductions ranged from **15–30%**, enhancing compliance with environmental thresholds. Noise measurements also showed an average reduction of **5–8 dB** compared to standard blasts.

6.4 Airblast and Dust Suppression

Air overpressure levels were significantly reduced, and dust emission monitoring showed up to **18% lower particulate concentrations** in downwind receptors due to controlled detonation sequencing and minimised high-frequency shock.

7. DISCUSSION

7.1 Operational Advantages

Chamber blasting demonstrates multiple benefits:

- **Enhanced fragmentation:** Reduces secondary breakage and improves processing efficiency.

- **Lower vibration and acoustic impacts:** Enhances safety in nearby infrastructure and residential zones.
- **Reduced explosive cost:** Improves operational economics.
- **Improved environmental compliance:** Aligns with sustainable mining frameworks.

7.2 Practical Challenges

Challenges include:

- Additional drilling for chamber preparation, which may raise initial operational cost.
- Requirement for precise initiation timing and skilled execution.
- Complex numerical modelling may be required for optimal chamber design.

These challenges can be mitigated through training, blast design software, and iterative field trials.

8. CONCLUSION

Chamber blasting represents a promising controlled blasting strategy that enhances both technical and environmental performance in opencast mining. Its ability to improve fragmentation, reduce explosive use, and mitigate environmental impacts aligns with sustainable mining goals and regulatory frameworks. The results of this research suggest that, with adequate design and testing, chamber blasting can be effectively implemented at scale in surface mining operations.

Future investigations are recommended to explore automated chamber design algorithms, integration with electronic detonator systems, and real-time blast optimisation using AI.

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