Field Evaluation of Stemming Plugs in Limestone Mining:

A Case Study at Sitapuram Limestone Mine, Zuari Cement Limited

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Abstract

Effective stemming is a critical yet frequently underestimated factor governing the utilisation of explosive energy in bench blasting. This paper reports the results of controlled field trials conducted at the Sitapuram Limestone Mine, the captive quarry of Zuari Cement Limited, located in Chintalapalem Mandal, Suryapet District, Telangana, India. Stemming plugs were deployed in half of a 29-hole blast to quantify their effect on rock fragmentation quality, muckpile throw, and per-tonne blasting cost relative to conventionally stemmed holes. The blast design comprised a staggered two-row pattern with 150 mm diameter holes, 8.5 m depth, 4 m burden, 5.5 m spacing, and ANFO as the primary blasting agent. Results indicate measurably improved fragmentation and greater muckpile displacement in the stemming-plug-assisted portion of the face. A preliminary cost comparison is presented. The findings corroborate the growing body of literature demonstrating that stemming plugs, by generating an air deck and reflecting a tensile stress wave within the borehole column, significantly enhance the efficiency of explosive energy utilisation without increasing drilling or explosives expenditure.

Keywords: *stemming plug, air deck, bench blasting, explosive energy, limestone quarry, fragmentation, ANFO, blasting efficiency, Explosives Saving, Blasting Cost Optimisation.*

1. Introduction

Blasting remains the most economical method of primary rock fragmentation in open-pit mining and civil construction. The quality of a blast, however, has far-reaching consequences for the entire downstream value chain: poor fragmentation increases loading and hauling cycle times, reduces crusher throughput, elevates grinding media consumption, and raises overall cost per tonne of product delivered.

Ammonium nitrate fuel oil (ANFO) is the dominant commercial explosive in Indian mining owing to its low unit cost and ease of bulk loading. However, ammonium nitrate is an energy-intensive product to manufacture, and global supply disruptions—driven by energy market volatility in key producing regions—have periodically constrained both availability and affordability of explosives for Indian mining operations. This reality has intensified the imperative for mining operations to extract maximum value from each kilogram of explosive consumed.

Among the available strategies for improving explosive efficiency, the following are most widely recognised:

- Use of higher-energy explosives and superior initiation accessories
- Optimisation of blast design parameters (burden, spacing, sub-drill, stemming length)
- Deployment of stemming plugs and air-deck techniques
- Application of borehole liners to improve coupling

While blast design optimisation has already been implemented to varying degrees across most Indian quarries, and the selection of explosives and accessories is largely determined by regulatory approvals and supply contracts, the use of stemming plugs represents a practical, low-cost intervention that can be adopted incrementally without disrupting existing operations. This paper reports on the first systematic trial of stemming plugs at the Sitapuram Limestone Mine operated by Zuari Cement Limited.

2. Objective of the Study

The primary objectives of this study were as follows:

- To evaluate the effect of PVC stemming plugs on rock fragmentation quality relative to conventional drill-cuttings stemming
- To compare muckpile throw and displacement characteristics between stemming-plug and non-plug sections of the same blast
- To quantify the cost differential per hole and per tonne of limestone between the two charging configurations
- To provide site-specific evidence that can support a decision on routine adoption of stemming plugs at Sitapuram Mine

3. Working Principle of Stemming Plugs

Stemming plugs are purpose-engineered devices inserted into a blast hole directly above the explosive column. Their function is to create a controlled air deck—a void of compressed air—between the top of the explosive charge and the base of the drill-cuttings stemming material. This configuration has been extensively studied in the blasting literature (Armstrong, 1994; Cevizci, 2013; Saharan et al., 2017; Oates and Spiteri, 2021) and is recognised as an effective means of enhancing explosive energy utilisation.

The mechanism operates as follows. At detonation, the explosive column generates a high-pressure, high-velocity detonation wave. As this wave propagates upward and encounters the air deck, the sudden change in acoustic impedance at the explosive-air interface causes partial reflection of the compressive wave back into the explosive and rock mass as a tensile wave. Rock is inherently far weaker in tension (typically 8–12 MPa tensile strength for competent limestone) than in compression (often exceeding 80 MPa for the same rock type). The induced tensile stress therefore drives preferential fracturing throughout the blast column, producing more uniform and finer fragmentation relative to a fully coupled charge with equivalent explosive weight.

Simultaneously, the detonation gases expand into the air deck, building pressure against the underside of the plug. This pressure loads the plug radially outward against the borehole wall, forming an effective mechanical seal. The seal prevents premature venting of detonation gases through the collar and instead redirects gas energy radially into the surrounding rock mass, extending the duration of the pressure pulse acting on the rock and thereby improving the work done per unit explosive mass.

Published studies report explosive savings in the range of 15–30% with air-deck configurations (Choudhary and Rai, 2013; Konya and Konya, 2017), alongside reductions in fly-rock, airblast overpressure, and ground vibration. The precise savings depend on the rock mass properties, explosive type, hole diameter, and air-deck length, and must be validated empirically at each site.

4. Site Description

The study was conducted at Sitapuram Limestone Mine, the captive mining operation of Zuari Cement Limited, located to the southwest of the Zuari Cement factory complex in Chintalapalem Mandal, Suryapet District, Telangana State, India. The mining lease area lies within the coordinates 16°48′32.5″–16°50′41.8″ N and 79°59’ 20.8″–80°02′28.4″ E as delineated on Survey of India Toposheets 56P/13, and 65D/1.

The mine is situated approximately 14 km from Jaggayyapeta (Krishna District) and 28 km from Kodad (Nalgonda District). The nearest railway connectivity is at Bonakallu station on the Kazipet–Vijayawada section of South Central Railway, approximately 50 km from the mine. The primary rock type at the site is limestone of the Nalgonda Formation, extracted for cement raw material.

5. Trial Design and Methodology

5.1 Blast Pattern and Hole Configuration

The trial blast comprised two rows of holes drilled in a staggered pattern, totalling 29 blast holes. The blast design parameters were as follows:

Parameter	Value
Number of holes	29
Pattern	Staggered two-row
Hole diameter	150 mm
Bench height	8.0 m
Average hole depth	8.5 m
Burden	4.0 m
Spacing	5.5 m
Primary explosive	ANFO

Table 1: Blast design parameters for the trial blast

5.2 Experimental Setup

To isolate the effect of stemming plugs, the 29-hole blast face was divided into two sections of approximately equal size. One section was charged conventionally, with drill cuttings used as the sole stemming material above the explosive column. The other section was charged identically in terms of explosive mass and configuration, with the addition of a PVC stemming plug inserted immediately above the explosive charge, creating an air deck of approximately 0.8 m before the conventional stemming was applied above the plug.

Photographs of the Face where trials were conducted

The stemming plug used was a PVC device designed to fold outward under detonation gas pressure, mechanically wedging against the borehole wall and preventing premature gas venting. Placement depth was controlled by the blast crew and verified by the trials supervisor. The front-row holes were stemmed to 3.0 m and the back-row holes to 2.5 m in both sections, ensuring that stemming length was not a confounding variable.

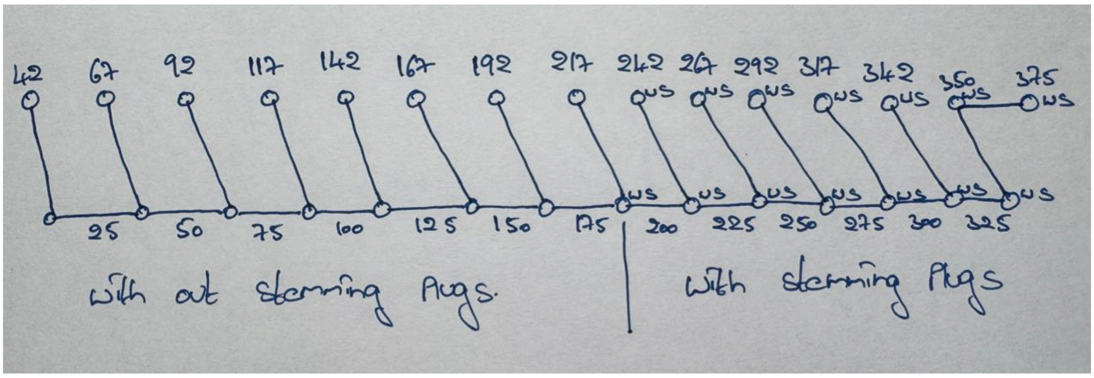


Fig 1 : The face plan showing the hole layout

Below the typical cross sections of holes with stemming plugs and holes charged with stemming plugs

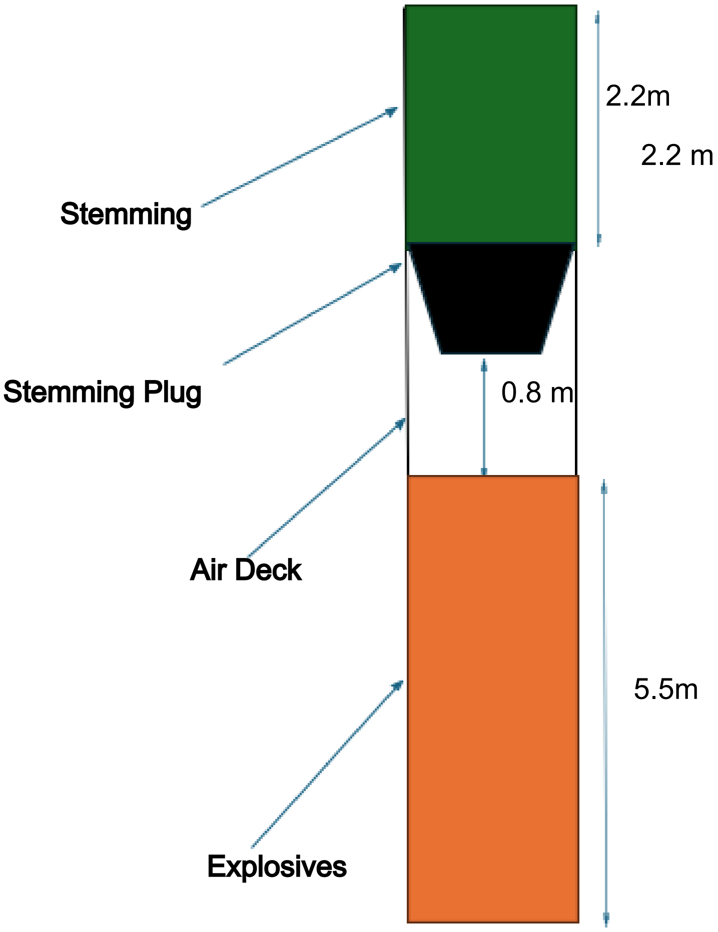
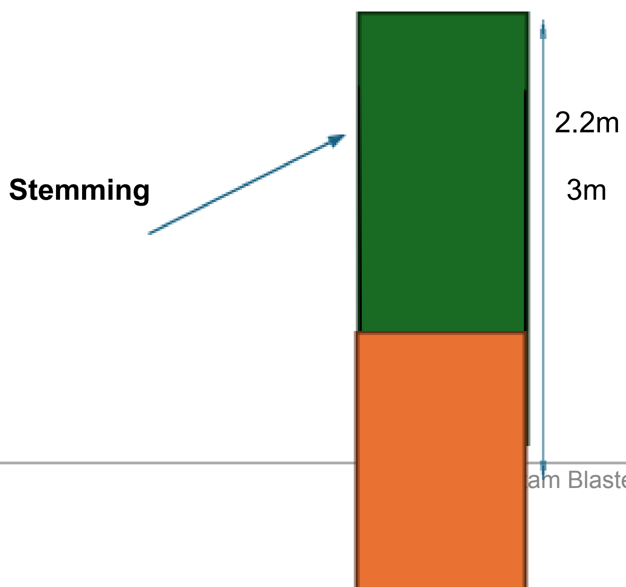


Fig 3

Below is the typical diagram of charging normally without stemming plugs



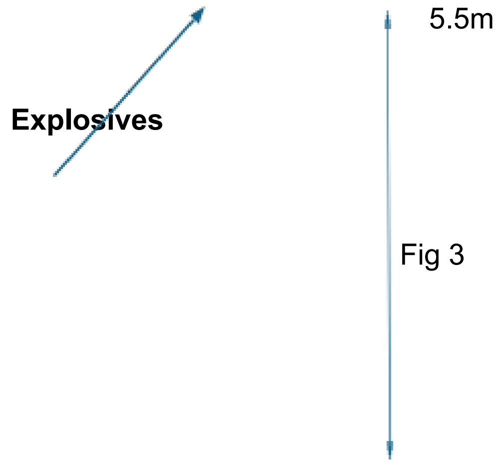


Fig 3

and plug/no-plug designation here, labelled as Figure 2. Cross-section diagrams showing the two charging configurations should be labelled as Figure 3.]

6. Observations

6.1 Fragmentation

Post-blast visual assessment of the muckpile indicated that the section of the face where stemming plugs were used produced noticeably improved fragmentation relative to the conventionally charged section. The proportion of coarse, oversized material visible in the muckpile was lower on the plug side, with the broken rock exhibiting a more uniform size distribution that would be expected to pass more readily through primary crusher feed grizzlies without secondary breaking.

With out Stemming Plugs **With Stemming Plugs**

Side where stemming plugs were used produced better throw than the normally charged side .

6.2 Muckpile Throw

The section charged with stemming plugs also demonstrated greater horizontal displacement of the broken rock mass (throw) compared to the conventionally charged section under identical delay timing and face geometry. Greater throw is generally associated with more complete utilisation of detonation gas energy and improved rock mass displacement and is a qualitative indicator of more efficient energy release. This observation is consistent with the findings of Choudhary et al. (2013) and Saharan et al. (2017).

7. Cost Comparison

A preliminary cost comparison was conducted to assess the economic implications of stemming plug adoption. The table below presents the charging cost structure for both configurations at the time of the trials

Cost Item	With Stemming Plug (INR)	Without Stemming Plug (INR)
Booster/Primer (725 g)	90	90
ANFO charge (Kgs per hole)	77.5 kgs	83 kgs
Cost of AN @ Rs 80.4 Per Kg	6231	6673
Stemming plug (per hole) @ 183	183	Nil

Total Cost Per Hole	**6504**	**6763**
Cost per Cubic Meter		
Out Put per Hole In Cubic Meter	176	176
Cost Per Cubic Meter in Rs	36.95	38.42
Saving Per Cubic Meter (INR)	1.47	—
Saving in Rupees Per Ton @ Density of 2.5 gms/cc	0.59	

Table 2: Cost comparison per hole – with and without stemming plug

It is noted that the use of stemming plugs not only reduce the cost of explosives to the extent of Rs 176 Per hole at the present price of Ammonium Nitrate of Rs 81 per Kg. It also produces better fragmentation and good throw.

8. Conclusions

The following conclusions are drawn from the field trial conducted at Sitapuram Limestone Mine:

- Use of Stemming plugs reduced the cost of Explosives to the extent of Rs0.59 Per Ton of Limestone with possibility of further reduction.
- Stemming plugs produced visibly superior rock fragmentation in the treated section of the blast face relative to the conventionally stemmed section, under identical blast design parameters and explosive loading.
- The stemming-plug-assisted section exhibited greater muckpile throw, indicative of more efficient utilisation of detonation gas energy.
- The technique is straightforward to implement within existing blast crew workflows and does not require modification of existing drilling or charging equipment.
- Further trials with a reduced ANFO column and extended air deck are recommended to explore the potential for direct explosive savings while maintaining or improving fragmentation outcomes.
- The findings support the adoption of stemming plugs as a routine practice at Sitapuram Mine, subject to confirmation of cost savings across a statistically larger number of blast events.

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