Blast Fragmentation Enhancement Using MOCAP VARI-STEM® Hole Plugs

By

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Abstract

This study was designed to quantify the effectiveness of the VARI-STEM® stemming plugs as they relate to improved rock fragmentation and overall blast performance.

The blasting operations during this study were conducted using electronic detonators. High levels of field controls were adhered to during the drilling and blasting process as they related to blast design, bench preparation, pattern layout, drilling and blast hole loading.

Following each blast, the fragmentation composite of the post blast muck piles were quantified using optical fragmentation analysis techniques. The crushing process was also studied to quantify any down stream advantages due to improvements in fragmentation.

This study will help provide the industry with more information as to the potential advantages gained through the proper use of borehole stemming plugs.

Introduction

Typically, the loss of explosive energy through stemming ejection reduces the performance of the blast. The fundamental theory promoting the use of stemming enhancement plugs is that they could potentially improve the effectiveness of stemming material in the blast hole. This would then in turn better contain the explosives energy within the rock mass and yield a more controlled and efficient blast event.

VARI-STEM® plug next to hole.

VARI-STEM® plug inserted into hole.

The 3 keys to efficient blasting are:

1. Energy Level – Amount of available energy in the explosive product.
2. Energy Distribution – Optimized linear distribution of the explosives in the rock mass.
3. Energy Confinement – Optimized burden to energy ratio.

The optimum stemming column height is determined so to provide proper energy confinement while still allowing for maximum explosive energy distribution in the borehole.

The measure of the potential effectiveness that the available explosives energy has to both break and displace the rock mass is directly proportional to the effective burden that energy must overcome. This relationship is a crucial element in basic blast design. An accurate controlled sequence of hole detonation is a fundamental design parameter having a major direct effect on overall blast performance. Any variation in hole detonation timing results in that hole being fired prior to or after its nominal firing time. The hole-to-hole detonation could still remain properly sequenced, or holes could potentially detonate totally out of sequence. This will result in burden to energy relationships that can have adverse impacts on the performance of a blast.

The results of these impacts have been witnessed in the past as:

- poor rock fragmentation.
- large amounts of oversize.
- high ground vibration levels.
- high air blast levels.
- flyrock incidents.
- high downstream processing costs.

Prior to the introduction of the VARI-STEM® stemming plugs at the Better Materials, Inc., Rich Hill Quarry in Connellsville, PA a previous study was conducted to quantify the realized benefits of electronic detonators over pyrotechnic initiation systems. This was an exhaustive study that yielded clear evidence demonstrating the increased blast performance and reduced overall mining costs through the use of electronic initiation. Following this study the Better Materials, Inc. Rich Hill Quarry has converted their stone production blasting operations over from a pyrotechnic non-electric shock tube initiation to a fully programmable electronic system. The on going use of the electronic detonators at this site has consistently yielded excellent blast fragmentation and high primary crusher throughput data.

The Rich Hill Quarry site was selected for this study because they have achieved a high level of blast optimization through their drilling and blasting practices. One of the key factors resulting in their blast optimization achievements has been that the negative effects of timing inaccuracy have been totally eliminated through with the use of the Daveytronic electronic initiation system.

The testing procedures conducted at the Better Materials, Inc., Rich Hill Quarry in Connellsville, PA were designed to provide data to quantify the MOCAP stemming plug's performance within the following parameters:

- Rock fragmentation
- Crusher throughput
- Blast control

A series of five production blasts would be monitored. The first two blasts would be initiated without using the VARI-STEM® plugs to establish baseline data and three blasts would be detonated using the plugs. The data would be analyzed and compared based on the above test parameters to determine overall benefits.

These blasts would be located in Bartley permit of the quarry. The maintenance of a high level of field controls during drilling, blasting and data collection processes to insure integrity of data was extremely important throughout the testing procedures. The five production blasts would all be symmetrical to one another in terms of their geometry and loading parameters.

Several of the test blasts were also filmed using a Redlake High - Speed Digital Video Recorder. The blast was filmed at a frame rate of 500 frames per second. The camera lens was zoomed to the surface of the bench directly above the first hole detonated in the face row of the blast. A surface electronic detonator was programmed with the same firing time as the in hole detonators of the explosive column below. This surface detonator was inserted into a box and placed directly above the blast hole collar.

The purpose of this test was to determine the amount of time elapsed (Δt) between the explosive detonation and the vertical heave and gas venting above the borehole. Any increase in this Δt would indicate a higher level of energy containment. This would enable the expanding gasses to potentially penetrate deeper into the micro-fractures of the rock mass, increasing fragmentation, before the gas pressure head is dramatically reduced with burden movement.

High Speed Digital Camera

Following each blast, the muck pile dimensions were documented and an optical fragmentation analysis was conducted throughout the excavation of the shot rock.

The primary crusher throughput was also monitored during the excavation of each blast. Previous studies have demonstrated a direct correlation between improved fragmentation and increased productivity.

Field Controls

Throughout this study, close attention was paid to maintain a high level of field controls. These field controls were monitored and applied as they related to:

- Bench preparation
- Pattern layout
- Blast hole drilling
- Blast hole loading procedures
- Post blast data collection

The implemented blast design during these test blasts utilized a 6-3/4 inch blast hole drilled to a bench depth of 55 – 60. Four rows of holes were drilled on a 15 ‘ X 20 ‘ staggered pattern. In order to insure proper toe burden dimensions, set back markers were placed prior to the detonation of each blast event to insure the proper placement of the following blasts face row of holes.

The production blasts were loaded using an Iremix, 40% emulsion blend. A 40 pound high energy toe load of SEC Sluran-600 was placed at the bottom of each hole prior to the bulk loading of the emulsion product. Prior to the blast hole loading each of the holes were again measured to verify the correct depth and the presence of water. If water was encountered, the holes were pumped prior to the introduction of explosives. The holes in the front row of each blast were stemmed with 9 feet of crushed rock. The holes in the second through forth rows were stemmed with 6 feet of crushed rock. In the blasts that utilized the VARI-STEM® stemming plug (part # SBP-6.5), 3 – 4 inches of stemming material (cuttings) were loaded above the powder column prior to the introduction of the plug followed by the crushed rock stemming to the top of the hole.

The explosive column rise was carefully monitored at each blast hole to insure the proper explosive column height and the designed amount of stemming material.

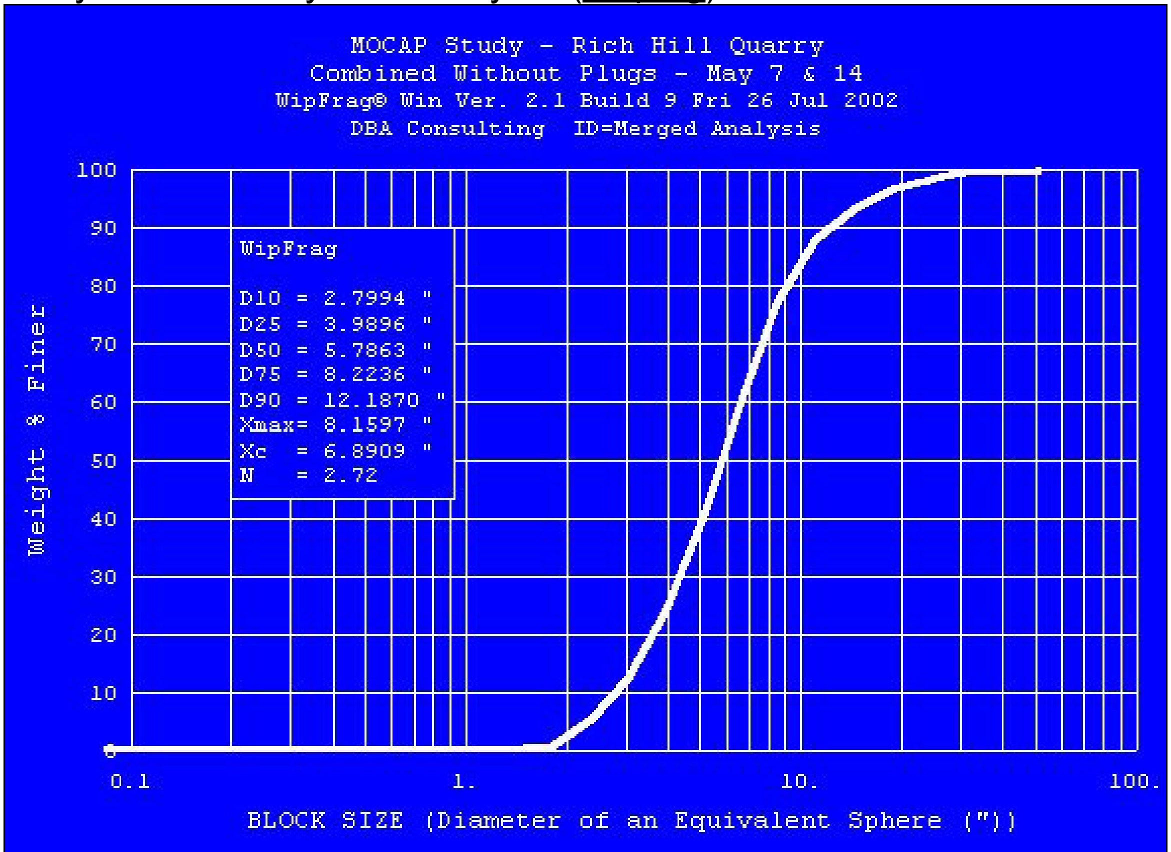
Fragmentation

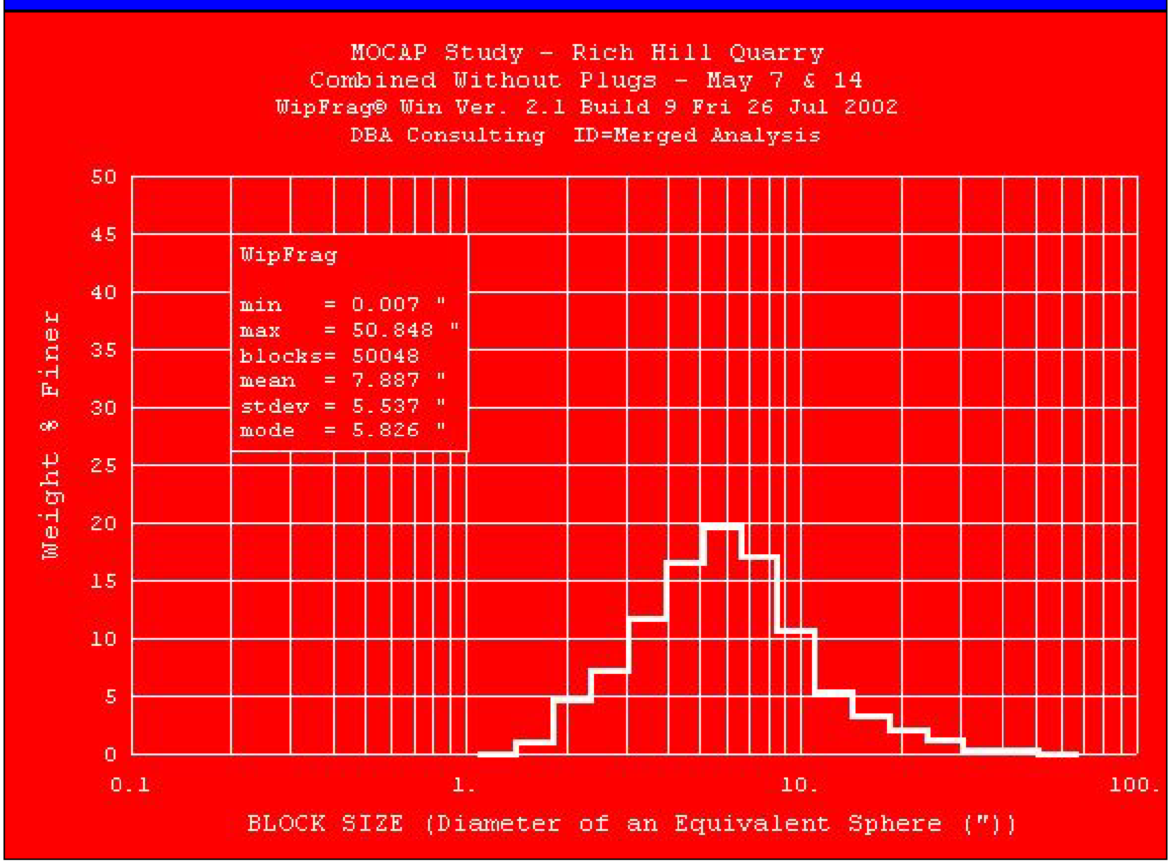
The fragmentation data during this study was processed using a digital image analysis system. The images were gathered using a Sony TRV-900 digital video recorder and a Sony Mavica CD-400 high resolution digital camera, transferred to disc and loaded into the image processor for delineation and size distribution analysis. The digital images were gathered during the excavation procedures at locations throughout the resulting muck piles to insure the merged findings would be representative of the true level of blast induced fragmentation. The images were obtained at the primary crusher as each truck load was emptied into the hopper.

The review of the video recordings of the blasts verified that a large percentage of oversize rock originates from the cap rock above the level to which the explosives could be safely or efficiently loaded to maintain proper confinement levels. This oversize material is directly related to the geologic conditions and blast geometry. The percentage of oversize in the post blast muck pile (2%) is the same for both the plugged and un-plugged blasts. Therefore, the fragmentation analysis was concentrated to the rock fragment sizes within the muck pile produced by the blast.

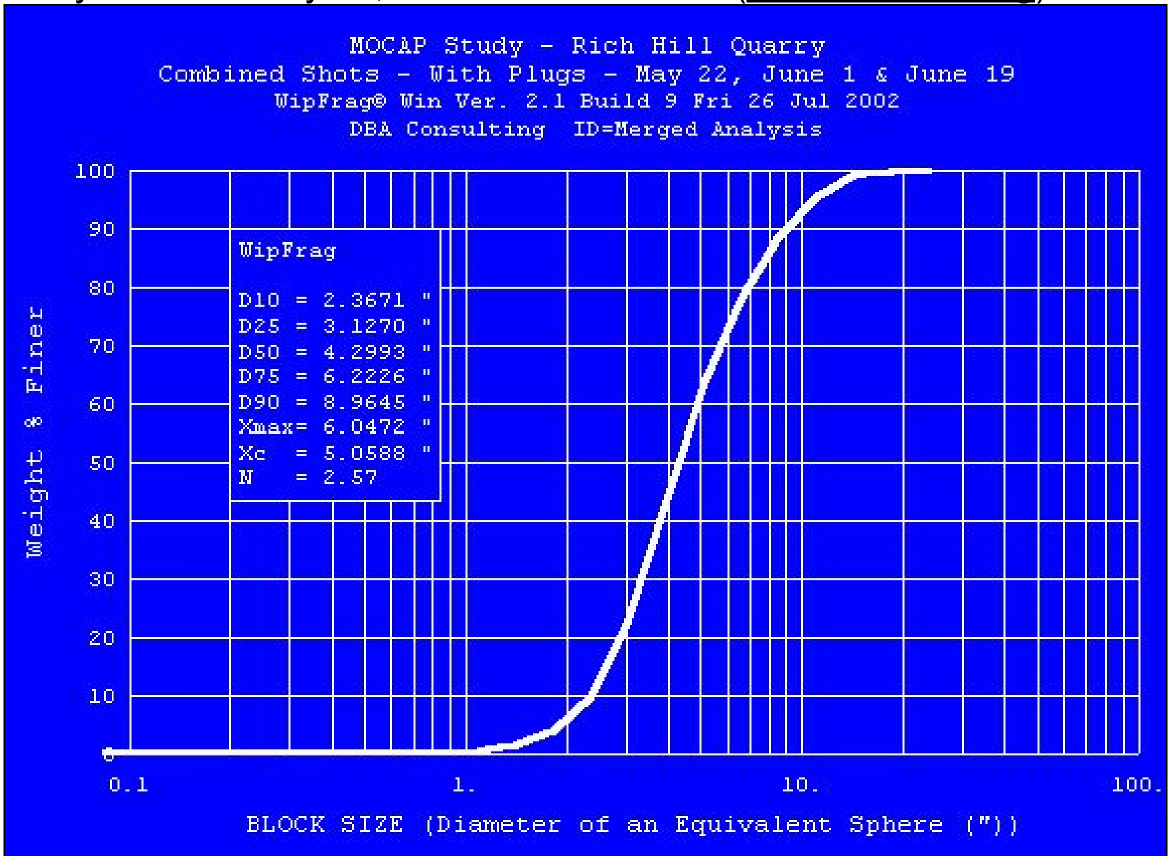
During the analysis of the images, the data files were saved in the system and used to create a merged analysis report. This report is very representative of the size distribution and uniformity of each of the resulting muck piles during the testing procedures. The analysis of the merged fragmentation data, yields results showing that the post blast muck piles of the test blasts utilizing the VARI-STEM® stemming plugs were composed of a higher degree of fragmented rock with a uniform size distribution.

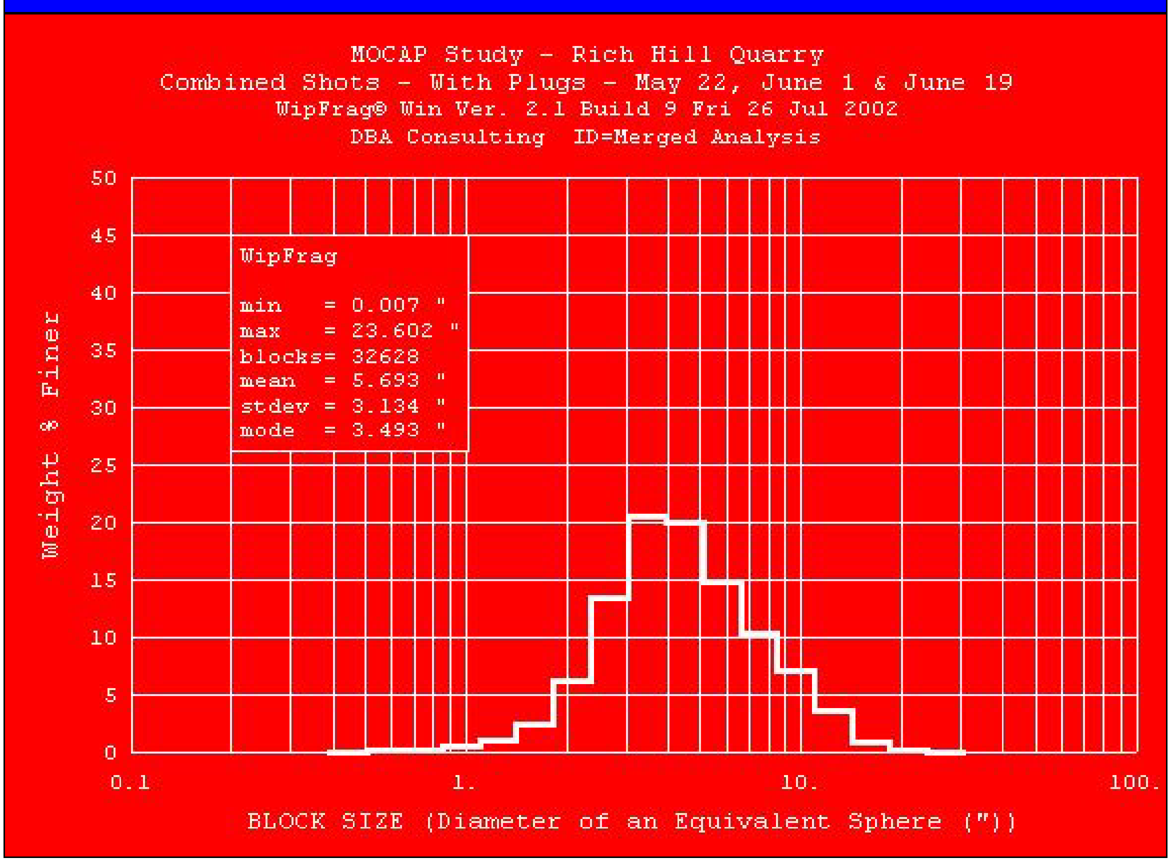
The following are the size distribution curve and the histogram for the combined analysis of the May 7 and May 14 (<u>no plug</u>) blasts.





The following are the size distribution curve and the histogram for the combined analysis of the May 22, June 1 and June 19 (VARI-STEM Plug) blasts.





The following chart contains the fragmentation from the individual blasts and the combined analysis of the plugged and non-plugged blasts. The chart includes the Mean Size, the D90 and D75 passing sizes and the Roslin – Rammler Uniformity Coefficient of the samples analyzed.

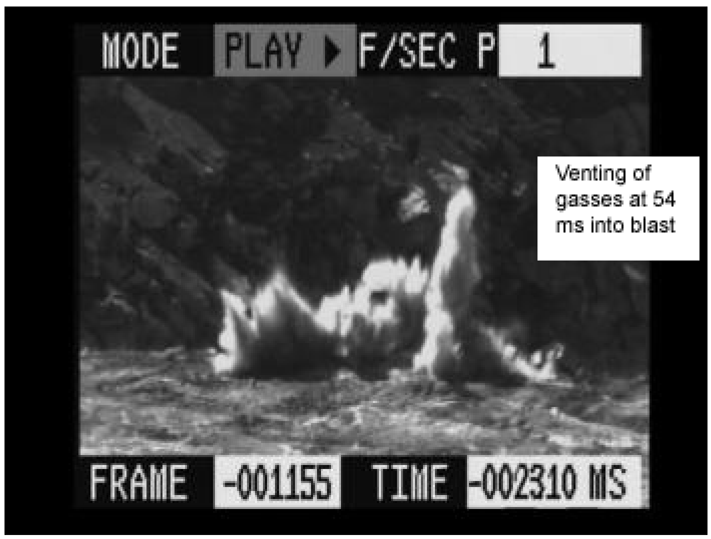
No Plug Blasts	**Mean Size (in)**	**D_{90} (in)**	**D_{75} (in)**	**Roslin - Rammler Uniformity Coefficient**
5/7/02	7.89	12.21	8.23	2.75
5/14/02	6.75	10.10	7.46	3.17
Combined Data	**7.89**	**12.19**	**8.22**	**2.72**
Plugged Blasts	**Mean Size (in)**	**D_{90} (in)**	**D_{75} (in)**	**Roslin - Rammler Uniformity Coefficient**
5/22/02	5.54	8.58	6.10	2.34
6/4/02	5.64	8.73	6.07	2.47
6/21/02	5.71	8.96	6.17	2.52
Combined Data	**5.69**	**8.96**	**6.22**	**2.50**

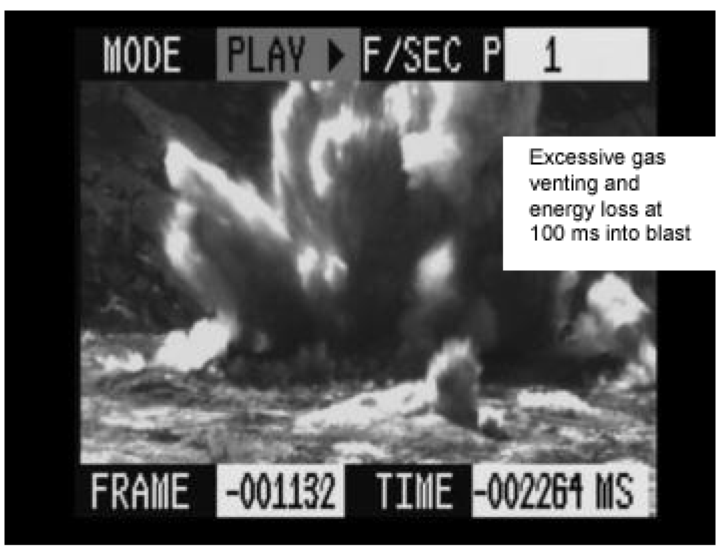
VARI-STEM® Stemming Plugs	% difference in avg. Mean size	Decrease in D_{90}	Decrease in D_{75}
Combined	**27% smaller ↓**	**26% ↓**	**24%↓**

The merged analysis of the MOCAP blasts resulted in a 27% reduction in the average mean size of rock and a 26% decrease in the D90 (90%passing) screen size from the combined no-plug result of 12.19 inches to 8.96 inches. There is also a 24% decrease in the D75 size from 8.22 inches to 6.22 inches. These numbers typically can be directly related to reductions in excavation and crushing costs. The 2.0 plus "Uniformity Coefficient" indicates a highly uniform muck pile.

Blast Control

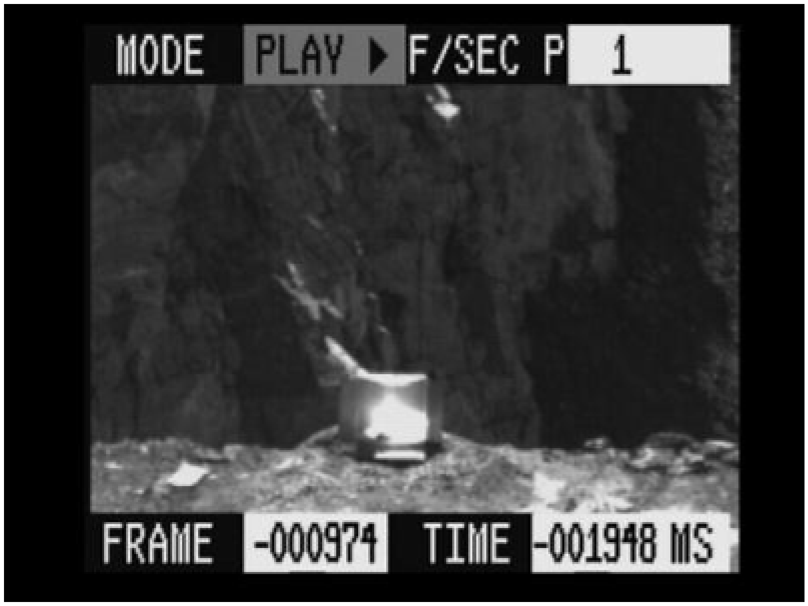
The high speed filming of the surface swell above the opening hole indicated that the stemming plugs effectively contained the expanding gasses roughly 3 times longer than the non-plugged holes using only crushed stone as the stemming material. The following images show the progression of each blast from initial detonation of the first hole to 100 milliseconds into the initiation.

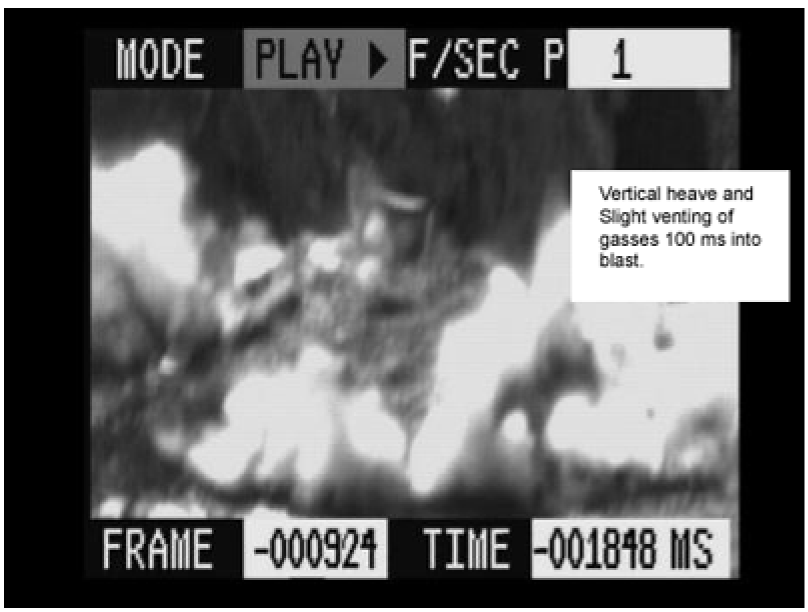




The above images of a non - plugged blast indicate a high level of gas energy release at 54 ms and 100 ms into the blast progression.

The above photos of a VARI-STEM® Plug blast show very little or no venting 100 ms into the blast.





The above photos of a VARI-STEM® Plug blast show little venting directly above the borehole 100 ms into the blast.

Productivity

The primary performance parameter monitored in this study was the crusher throughput. During the shifts while the primary crusher is operating, records were kept regarding the source and the total tonnage of the stone delivered to the primary during each shift.

According to the operators' records, the summary of the data is as follows:

Test Blast 1, Bluestone Blast on 5/7/02, no plugs used.

Day Shift

Date	Hours	Tons	Tons/Hr
5/7/02	9	7640	849
5/8/02	9	7392	821
5/9/02	9	9230	1026
5/10/02	9	7333	815
5/11/02	7	7024	1003
5/13/02	9	7252	806
		Total Tons	Average
		45871	887

Night Shift

Hours	Tons	Tons/Hr
6	5775	963
8	6240	780
8	8271	1034
8	5694	712
	Total Tons	Average
	25980	872

Test Blast 2, Bluestone Blast on 5/14/02, no plugs used.

Day Shift

Date	Hours	Tons	Tons/Hr
5/14/02	9	7260	807
5/15/02	9	8166	907
5/16/02	9	9170	1019
5/17/02	9	9124	1014
5/18/02	7	5328	761
5/20/02	9	7882	876
5/21/02	3	499	166
		Total Tons	Average
		47429	793

Night Shift

Hours	Tons	Tons/Hr
7	6678	954
7	5681	812
7	6171	882
6.75	5409	801
7	5786	827
	Total Tons	Average
	29725	855

The average throughput of Test Blast 1 and 2, blasts loaded without stemming plugs, was 851 tons per hour. The following are the summaries of the data corresponding to the three VARI-STEM® stemming plug blasts.

Test Blast 3, Bluestone Blast on 5/22/02, stemming plugs used.

Day Shift				Night Shift		
Date	Hours	Tons	Tons/Hr	Hours	Tons	Tons/Hr
5/22/02	8	7004	876	5.75	5917	1029
5/23/02	7.75	6464	834	5.75	4543	790
5/24/02	8	6646	831			
5/25/02	6	6586	1098			
5/28/02	8	7697	962	5.75	5386	937
5/29/02	7	5922	846	6	6151	1025
5/30/02	8	4653	582	6	4515	753
5/31/02	7	5306	758	2	1754	877
		Total Tons	Average		Total Tons	Average
		50278	848		28266	902

Test Blast 4, Bluestone Blast on 6/1/02, stemming plugs used.

Day Shift				Night Shift		
Date	Hours	Tons	Tons/Hr	Hours	Tons	Tons/Hr
6/1/02	5	2329	466			
6/3/02				4.5	3187	708
6/4/02	7.5	7268	969	5.75	4898	852
6/5/02	7	6802	972	3	3139	1046
6/6/02	6	4549	758			
6/7/02	2	2358	1179	7	5874	839
6/8/02	6	5849	975	4.33	4009	926
6/10/02	7.5	7258	968	5.75	4728	822
6/11/02	8	7507	938	6	6056	1009
		Total Tons	Average		Total Tons	Average
		43920	903		31891	886

Test Blast 5, Bluestone Blast on 6/19/02, stemming plugs used.

Day Shift				Night Shift		
Date	Hours	Tons	Tons/Hr	Hours	Tons	Tons/Hr
6/19/02	6	4685	781	6	5146	858
6/20/02	8	7772	972	5	4964	993
6/22/02	6	4692	782			
6/24/02	8	6789	849	6	5672	945
6/25/02	6	4896	816	6	4689	782
		Total Tons	Average		Total Tons	Average
		28834	840		20471	894

The average primary crusher throughput of stone during the excavation of the baseline test blasts was 851 tons per hour. The average primary crusher throughput of stone from the VARI-STEM® plugged blasts was 879 tons per hour. This represents a 3% increase in stone throughput at the primary crusher.
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Conclusion

The VARI-STEM® Plug trials that were conducted at the Better Materials Inc., Commercial Stone Operation: Rich Hill Quarry during the period from May 7, 2002 through June 21, 2002 resulted in performance benefits in terms of improved fragmentation and increased primary crusher productivity.

The findings during this study at the Rich Hill quarry provide positive evidence quantifying the benefits of stemming plugs in terms of improved blast performance as typified by:

- A 27% decrease in the mean size of rock in the post blast muck pile from 7.89 to 5.69 inches.

- A 3% increase in the tonnage throughput at the primary crusher.

This testing was conducted in such a manner to demonstrate the potential productivity increase and downstream savings borehole stemming plugs can provide. It is the opinion of DBA Consulting that similar test results could possibly be obtained conducting the same testing procedures using pyrotechnic initiation systems in place of the electronic detonators. However, the use of electronic detonators to eliminate timing scatter significantly increases the reliability of the studies findings and may be directly related to the effectiveness of the stemming plug.

Respectfully Submitted,

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