# The Importance of Energy Containment to the Blast Outcome & Justification for use of Stemming Plugs in Over Burden Removal

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## Abstract

Blast energy can be divided into two components: **Applied energy** – shock & heave energy used in material breakage; **Lost energy** – manifests itself as air over-pressure, ground vibration & excess fines (over-blasted material).

Stemming is inert material used to confine energy in the blast hole at the top of the explosive charge. Insufficient, inconsistent or inefficient stemming allows the blast energy to prematurely vent at the collar, reducing the energy applied to breaking & moving the rock mass. Stemming ejection is a common cause of lost energy in the blast, especially when drill cuttings are used. A series of case studies shall be presented to examine how stemming efficiency may be increased with the correct use of a stemming plug.

*Keywords: fragmentation, stemming, stemming plug, rock breakage, drill & blast, air blast, fly rock.*

## 1. Introduction

Breaking rock is the first step in the mining process, and is done so the material can be moved to a different location for waste dumping, stock piling and/or further processing. The use of explosives to break rock is recognised as the lowest cost option when the rock cannot be free-dug or continuously mined due to its geological characteristics.

## 2. The mining process.

Mining can be divides into four distinct processes: (1) Drill & Blast; (2) Digging; (3) Hauling; and (4) Processing. As a process mining can be considered energy-intense because each stage requires some form of energy use (fuel & chemical energy in drill & blast, fuel energy in dig & haul and electrical energy in processing). At this time all this energy is provided by predominantly non-renewable sources, and due to increasing scarcity the cost of these energies can only increase over time.

Drilling and blasting rock with explosives is performed when it is considered the lowest cost means of breaking the rock sufficiently small enough so it can be dug and transported elsewhere for either waste dumping (in the case of stripping) or stock piling for further processing.

We can divide blast energy into two main components: **Applied energy** – shock & heave energy used in material breakage; **Lost energy** – manifests itself as air over-pressure, ground vibration & excess fines (over-blasted material). Our goal in sustainable and profitable mining is to maximise the applied energy and reduce the lost energy to the highest extent possible.

There are three acknowledged keys to efficient blasting of material for the purposes of further processing: (1) **Energy level** – the amount and type of energy contained within the explosive product; (2) **Energy distribution** – the optimised linear distribution of the explosive energy within the rock mass; (3) **Energy confinement** – the optimised energy to burden ratio to balance the need to confine the energy while allowing maximum explosive energy distribution within the rock mass. It is important all three aspects of energy in blasting work in unison, because it can be shown that in many cases of inefficient or unpredicted blast outcomes one or all of these aspects are the reason for the result.

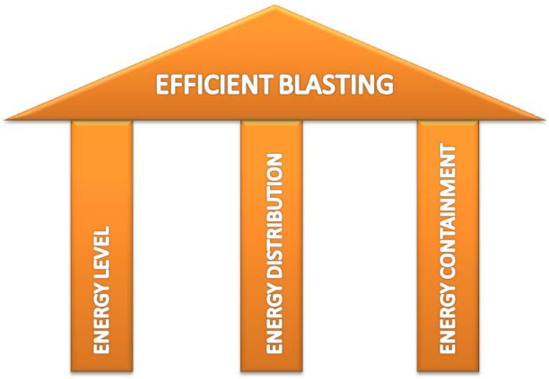


**Figure 1**: 3 keys to efficient material blasting

### 3. Stemming materials & height

Stemming is inert material used to confine energy in the blast hole at the top of the explosive charge. Insufficient, inconsistent or inefficient stemming allows the blast energy to prematurely vent at the collar, reducing the energy applied to breaking & moving the rock mass. The optimum stemming column height is determined so to provide proper energy confinement while still allowing for maximum explosive energy distribution in the blast hole. Stemming ejection is a common cause of lost energy in the blast, especially when drill cuttings are used.

**Figure 2**: Stemming ejection during blasting

Typically, loss of explosive energy through stemming ejection reduces the performance of the blast, resulting in: (1) Poor fragmentation & oversize boulders in the blasted material; (2) Air blast & flyrock issues that impacts people and infrastructure in proximity to the blast area; (3) Increased down-stream processing bottlenecks and costs caused by secondary processing (blasting or mechanical rock breaking) or excessive circulation within the processing circuits.

There are a variety of materials used for stemming the blast hole, and one must consider the density of these materials as it affects the ability of the material (through its inertial characteristics) to prevent premature venting of the expanding explosive gases and by extension increase the amount of material breakage during the explosion process.

| Material | Density (kg/m$^3$) |
|---|---|
| Earth –loose mud | 1730 |
| Earth – packed | 1522 |
| Gravel - loose, dry | 1522 |
| Sand – wet | 1922 |
| Sand – wet & packed | 2082 |
| Sand – wet w/ gravel | 2020 |
| Sandstone – broken | 1450 |
| Water | 1000 |

**Table 1**: Density of common stemming materials.

A commonly accepted heuristic (rule of thumb) for determining the correct stemming height is to relate the stemming height to the hole diameter multiple in a range of twenty to thirty times the hole diameter (i.e. 20Ø to 30 Ø). While there will be occasions to have a stemming height above or below this range for reasons determined by the geology and/or blasting outcome desired, this heuristic has proven itself over time.

Aspects that will determine at where in the range of 20 to 30 time hole diameter (Ø) range the stemming height should be will be:
(1) Rock strength;
(2) Hole size;
(3) Charge energy of the blast;
(4) Burden size & strength;
(5) Water within the blast hole;
(6) Portion of loose material [such as drill cuttings] contained in the stemming material.

As a general rule, as any of these aspects increase, the stemming height should increase, from 20x Ø to 30x Ø, as well. We shall call this **The 20-30 rule**. If the example of a Ø200mm hole is considered, the stemming height range will be between 4.0m (20 x 0.2m) and 6.0m (30 x 0.2m). As any of the aforementioned aspects increase (rock strength, charge energy, burden etc.) consideration should be given to setting the stemming height higher within the 4.0m to 6.0m range.

An empirical measure of blast energy confinement is scaled depth of burial (SD). Scaled depth can be described as ratio of the stemming material to the amount of explosive within a space equivalent to ten hole diameters.

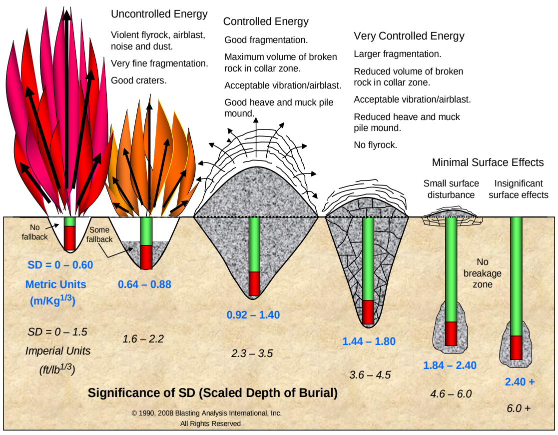


**Figure 3**: Scaled depth of burial (Courtesy BAI).

As shown in Figure 3 above, if the stemming height is inadequate (that is, the ratio of stemming material to explosives in 10xØ is low) the energy release is uncontrolled, with the majority of the blast energy manifesting itself in nuisance such as fly rock and noise and the minority of the energy applied to rock breaking. Under-stemming is a common occurrence due to stemming inadequacy, inconsistency or inefficiency. Conversely if the stemming height is excessive, the blast energy is choked and inadequate rock breakage takes place with resultant oversize and associated costs of remediation.

To verify The 20-30 Rule, consider the following example:

Hole Ø = 200mm
Stemming height ($S_t$) = 4.0m
Explosive density (ß) = 1.15g/cc
Explosive loading density $ß_{load}$
= 36.13kg/m (from tables)

Length of 10 explosive diameters (L)
= Ø x 10
= 2.0m

Explosive within 10 explosive diameters (W)
= $ß_{load}$ x L
= 36.13 x 2.0 = 76.26kg

Distance from surface to centre of W (D)
= $S_t$ + (0.5 x L) = 4.0 + 1.0
= 5.0m

Scaled depth of burial (SD)
= $D / W^{0.333}$
= $5.0 / 76.26^{0.333} = 1.18\ m/kg^{0.333}$

From the calculation we can see a stemming height equivalent to 20 hole diameters falls within the 'Controlled Energy' range for scaled depth of burial (SD) being 0.92 to 1.40m/kg $^{0.333}$, the SD being 1.18 m/kg $^{0.333}$ in this case.

## 4. Detonation sequence effect

Poorly designed or executed timing sequences can adversely affect the burden to energy relationship & cause explosive malfunction such as cap or shock desensitisation of the explosive product, and sympathetic detonation caused by the unscheduled firing of a near-by charge.

One must remember that delay detonators may 'slow down' with age and that proper stock management and rotation (generally first in-first out methodology) must be employed at the magazine.

The timing precision & accuracy of electronic detonators has been proven to improve fragmentation & mining productivity while reducing down-side effects mentioned earlier.

## 5. **Improving stemming efficiency**

Stemming plugs in their various forms have been available for many years and a number of published case studies have proven their worth when used properly and with cognisance of the keys to efficient blasting mentioned previously, namely energy level, energy distribution & energy confinement.

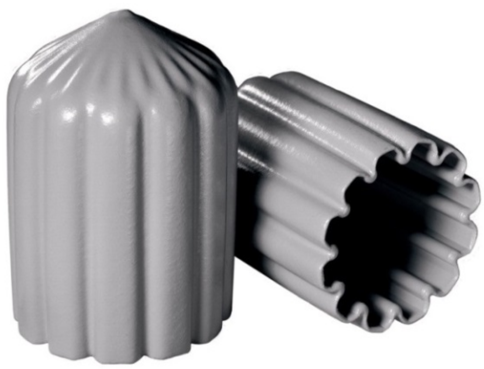

**Figure 4**: Vari-Stem stemming plugs

Characteristics of a good stemming plug will be:

- Good contact with the blast hole wall
- Ability to improve fragmentation
- Ability to increase applied energy in the blast
- Ability to improve productivity
- Ability to lower air blast & vibration
- Simple deployment
- Potential to increase pattern spread to generate drill-fill-fire savings

Consistent stemming height has been proven to result in greater consistency in fragmentation in the upper flitch of the blast, but this can be difficult to achieve without good quality control of the drilling and explosive loading processes. If for instance, holes are drilled to different depths, this needs to be compensated for. Similarly if the holes inadvertently back fill between time of drilling and time of explosive product loading (through egress of drill cuttings from the surface) this needs to be compensated for. While the explosive loading is accurately calculated and subsequently controlled (through automation fitted to most bulk explosive loading trucks these days) the amount of stemming, while calculated as part of the blast design process, is rarely measured, monitored or controlled on the bench. Generally the operator 'fill to collar' regardless of what amount that actually represents, and as a consequence the stemming height across the shot has little chance of consistency.

The use of a stemming plug allows the opportunity to check the stemming height prior to installing the plug. The loading pole used to install the plug can be used to check the distance from the blast hole collar to the surface of the explosive product. If the explosive is an emulsion product, the operator must wait for the product to 'gas' and achieve its design density & expansion (refer to the explosive manufacture for their recommendation on timing).

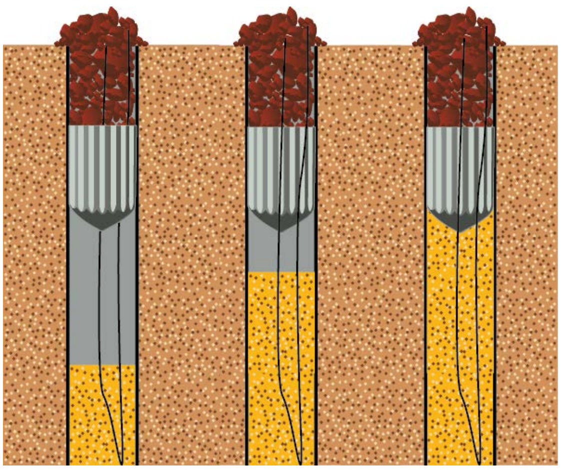

**Figure 5**: Achieving consistent stemming height with Vari-Stem stemming plugs

Some considerations regarding the use of stemming plugs are:

- Plugs are not a substitute for good blast design. If the blast design is fundamentally flawed installing a stemming plug will not fix this.
- Plugs cannot defy the laws of physics. If there is insufficient stemming material (and by extension insufficient inertia the material can provide) a stemming plug cannot compensate totally for this.

- Plugs enhance explosive energy, not create it. As mentioned previously, if one of the keys of efficient blasting (energy level) is incorrect a stemming plug cannot compensate for this.
- Plugs enhance stemming performance, not replace it. Again, if one of the keys of efficient blasting (energy confinement) is incorrect a stemming plug cannot compensate for this.
- Stemming plugs can be used in full column charge and decking applications. When full column charging with emulsion it is advised to place a small amount of drill cuttings (approximately one hole diameter length) before installing the plug to increase resistance to the initial heat wave and shock resistance of the plug.
- Creating a small deck above the explosive charge when loading emulsion can prevent dead-pressing, a phenomenon that occurs if the emulsion has not completely gassed before the hole is stemmed, preventing the explosive from achieving the proper density and doing so can cause high order of detonation problems.

**Figure 6**: Installing Vari-Stem stemming plugs

Tangible evidence of the efficacy of using Vari-Stem plugs can be seen in the delay in venting of the explosive gases of detonation and a reduction in stemming material ejection in the blast. Below are some high-speed video images of a blast to emphasise the point. The longer the explosive gases take to vent at the surface and the reduction of stemming ejection, it follows that the more breakage of rock below the surface takes place. Said another way, delay in time to movement exhibits an increase in applied energy and a reduction in wasted energy.

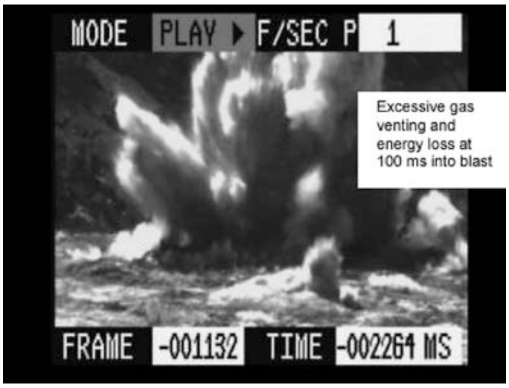


**Figure 7**: Blast at 100ms, without Vari-Stem plugs


**Figure 8**: Blast at 100ms, with Vari-Stem plugs showing reduced upward ejection & increased radial heave.

The use of electronic detonators to eliminate timing scatter can significantly increase the effectiveness of the stemming plug but is has been shown that good quality non-electric detonation with low scatter characteristics provide good performance as well

### 6. Blast pattern spread

The ability to maintain a target fragmentation while increasing the spacing in the pattern to effectively reduce drill-fill-fire costs of any mining or quarrying operation is seen as a major justification in the use of plugs in the face of downward pressure on the global price of all commodities and rising energy costs.

Where applied correctly and with cognisance of the correct level of energy level (powder factor), energy distribution (burden, spacing & bench height) and energy confinement (scaled depth of burial), Vari-Stem plug have been proven to yield improved overall fragmentation than the current pattern. Further, if in the clients' view the current fragmentation with existing pattern is deemed sufficient, the pattern could be expanded with the implementation of the Vari-Stem plugs thus reducing the number of holes drilled for the same volume of rock.

### 7. Plug installation procedure

The following is a guide to correct installation of stemming plugs such as Vari-Stem.

- Store boxes in a dry area to prevent premature deterioration of the packaging.
- Vari-Stem™ is not classified as dangerous goods for transport, storage & handling, so ships and stores as general cargo under the United Nations code. It is constructed of inert plastic material and has a virtually infinite shelf life as long as the product is correctly stored and packaging is intact. The weight of each box will vary due to the number & size of plugs in a range of approximately 4.5 to 16.5kg, requiring only standard personal protection equipment (PPE) and manual handing procedure as required by law and/or site regulation.
- Each box contains a quantity of stemming plugs depending on the size (smaller blast hole sized units ship more to a standard box, and visa versa). A plug may contain a cardboard ring to keep the shape intact during transport. In the 9.00"/229mm size the ring is left inside the product during deployment, all other sizes the ring is removed prior to deployment.
- If the plug has distorted in shipping and/or storage, merely stretch the plug back into shape.
- If emulsion explosive has been loaded, wait for at least 30-45 minutes for the emulsion to gas (please consult the explosive manufacturer for confirmation of this value) before loading the stemming plug. Loading prematurely can cause 'dead pressing' of the explosive that could prevent it achieving the correct detonation characteristic, or prevent detonation at all.
- Have a loading pole long enough to push the plug into position. The correct stemming height is generally in a range of 20 to 30 times the blast hole diameter depending on quality of the stemming material, presence of water in the top portion of the hole, powder factor, rock strength in the upper flitch, and burden. The depth should be clearly indicated on the pole for the benefit of the operator, and to ensure consistency from hole-to-hole across the shot.
- In dry ground push the plug to the desired depth with the loading pole. With wet hole, pushing into position may be slower as the water needs to pass the geared profile of the plug. The geared profile of the plug is designed not to damage down lines & cords. If needed, place some rocks on the cup of the plug to assist in deploying in wet ground. This procedure results is consistent stemming heights across the entire shot, which in turn contributes to consistent & improved fragmentation results.
- After using the loading pole push the plug to the desired depth representing the bottom of the stemming, manually

put some stemming material in the hole, enough to fill the cup of the stemming plug at least, more is better. This helps lock the plug in position, and cushion any shock from stemming material dropping into the initial position.

- In wet ground, water will be displaced by the stemming material. If any tamping of the stemming material (especially if the stemming is drill cuttings or a significant percentage of drill cuttings) extreme care must be taken not to cause any damage to down lines and cords in the stemming area. Only trained & experienced operators should perform this task.
- After stemming has been loaded and during final inspection prior to firing the shot ensure all holes area stemmed to surface level at least, and no holes show signs of subsidence of the stemming material. Subsidence can occur when drill cuttings are used as stemming in wet ground or if the stemming plug has moved, and any change to the down lines (such as increased tension or evidence of movement) should be carefully remedied or at least recorded in case it is relevant to any post-blast analysis.

## 8. Case study

To determine if use of the Vari-Stem plug can be justified one must look at the process of over burden removal in a holistic way that includes dig & haul rates, rather than a cost-per-hole-basis. The latter is an incomplete analysis that ignores the fact that as we progress along the drill-to-dump continuum in over burden removal the cost of energy steadily increases. In other words, blast (chemical explosive) energy is the lowest form of energy to break rock, lower than fuel energy (otherwise free-digging would replace drill & blast).

Consider the following scenario:

| **Variable** | **Actual** | **ROT*** |
|---|---|---|
| Hole Ø: | 200mm | |
| Burden: | 8.0m | 5.0 – 8.0m |
| Spacing: | 8.5m | 5.8 – 9 2m |
| Bench Height: | 10.0m | 13.3m |
| Sub drill: | 1.0m | 0.6 – 3.0m |
| Stemming height: | 5.5m | 3.5 – 6.0m |
| Charge height: | 5.5m | 5.0m |
| Stemming material: | Cuttings | |
| Stemming density: | 1522Kg/m$^3$ | |
| Explosive density: | 1150Kg/m$^3$ | |
| Vari-Stem plug: | US$10.00 | |
| Cost of explosive/m: | US$27.00 | |
| Drilling cost/m: | US$2.73 | |
| # holes/blast: | 200 | |
| Rock strength: | 3-20 MPa | |
| Stripping ratio: | 12:1 | |
| Coal margin: | US$10.00/T | |
| **Hole attributes:** | | |
| Average hole length: | 11m | |
| Charge per hole: | 199kg | |
| Hole charge volume: | 173 litres | |
| Hole volume: | 346 litres | |
| Charge length: | 5.5m | |
| Average charge/m: | 36kg/m | |
| **Blast attributes:** | | |
| Blast volume: | 136,000m$^3$ | |
| Charge weight: | 39,750kg | |
| Total drill metres: | 2,200m | |
| Powder factor/BCM: | 0.29kg/m$^3$ | |
| Powder factor/T: | 0.11kg/T | |
| Rock in blast (T): | 350,880T | |
| **Blast statistics:** | | |
| # Hole Ø in stemming height: | 27.5 | 20 – 30 |
| # Hole Ø in sub drill: | 5 | |
| Burden per Spacing ratio: | 1.06 | |
| Burden stiffness ratio: | 1.25 | 2.00 – 3.5 |
| # Hole Ø per bench height: | 50.0 | |
| # Hole Ø per burden: | 40.0 | |

**Table 2**: Vari-Stem plug case scenario criteria

**ROT – Rule of thumb (heuristic) values (Source: Dyno Nobel Asia Pacific, 2010).*

**Figure 9**: Typical coal mine geology.

On the basis outlined here, the column is fully charged with no gap between the explosive product and the stemming material.

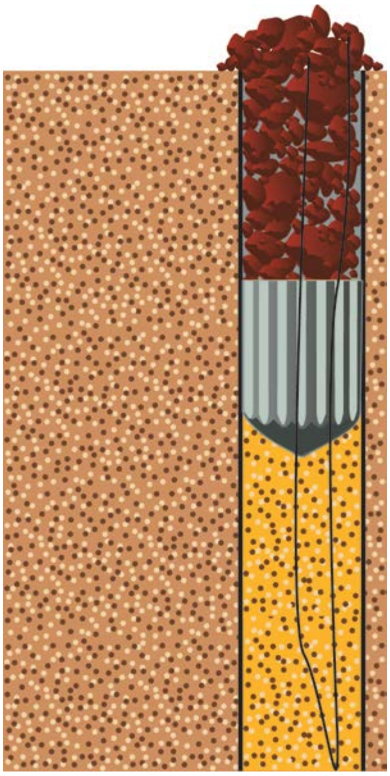

**Figure 10**: Full charge in current scenario (NTS).

**Reduce stemming height**

Consider reducing stemming height (everything else unchanged) using the Vari-Stem plug. Firstly, a check of the scaled depth of burial the current stemming height:

Hole Ø = 200mm
Stemming height ($S_t$) = 5.5m
Explosive density (ß) = 1.15g/cc
Explosive loading density $ß_{load}$
= 36.13kg/m (from tables)

Length of 10 explosive diameters (L)
= Ø x 10
= 2.0m

Explosive within 10 explosive diameters (W)
= $ß_{load}$ x L
= 36.13 x 2.0 = 76.26kg

Distance from surface to centre of W (D)
= $S_t$ + (0.5 x L) = 5.5 + 1.0
= 6.5m

Scaled depth of burial (SD)
= $D / W^{0.333}$
= $6.5 / 76.26^{0.333} = 1.54$ m/kg $^{0.333}$

From the calculation we can see a stemming height equivalent to 27.5 hole diameters falls outside the 'Controlled Energy' range for scaled depth of burial (SD) (Figure 3, pp.3) being 0.92 to 1.40m/kg $^{0.333}$, the SD being 1.54 m/kg $^{0.333}$ in this case.

Consider reducing stemming height to 4.5m (everything else unchanged) using the Vari-Stem plug:

Hole Ø = 200mm
Stemming height ($S_t$) = 4.5m
Explosive density (ß) = 1.15g/cc
Explosive loading density $ß_{load}$
= 36.13kg/m (from tables)

Length of 10 explosive diameters (L)
= Ø x 10
= 2.0m

Explosive within 10 explosive diameters (W)
= $ß_{load}$ x L
= 36.13 x 2.0 = 76.26kg

Distance from surface to centre of W (D)
= $S_t$ + (0.5 x L) = 4.5 + 1.0
= 5.5m

Scaled depth of burial (SD)

$= D / W^{0.333}$
$= 5.5 / 76.26^{0.333} = 1.30\ m/kg^{0.333}$

From the calculation we can see a stemming height equivalent to 22.5 hole diameters falls inside the 'Controlled Energy' range for scaled depth of burial (SD) (Figure 3, pp.3) being 0.92 to 1.40m/kg $^{0.333}$, the SD being 1.30 m/kg $^{0.333}$ in this scenario.

**Creating a deck**

A deck, a gap between the surface of the explosive product and the bottom of the stemming plug, is a proven technique to improve rock breakage by creating a space that pressure waves of detonation may collide and create pulsations in increase micro-fractures in the rock mass. (Refer numerous references in the Acknowledgements & References area in this paper)

Decking also creates a space for emulsion explosives to expand into (if the required gassing time was not observed for whatever reason) to prevent dead-pressing of the emulsion, that prevents the emulsion achieving its target gassing density. Decking can be facilitated and enhanced with the use of Vari-Stem plugs due to the additional time to movement in the blast (that delays surface venting) caused by the plugs resistance to the pressure & temperature waves generated in the blast.

Reducing the stemming height to achieve scaled depth within the correct range with the use of the Vari-Stem plug to support the stemming material above the explosive is a simple way to create the deck, especially if the initial view is the powder factor cannot be lowered without resulting in the presence of oversized boulders in the upper flitch / stemming area. A body of research has taken place in establishing how large the deck volume can be relative to the total volume and the effect on the mean fragment size. This relationship is shown in the following graph.

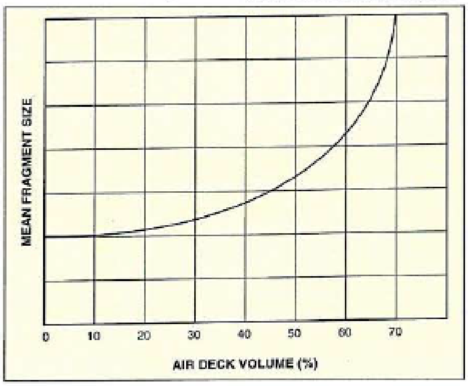


**Figure 11**: Relationship between air deck volume and mean fragmentation time. *Source: Cleeton, J. (1997).*

It will be noted that a deck of up to 20% of the blast hole volume will have little effect on the mean fragment size due to the effect of the secondary pulses and the time delay created within the deck during detonation, especially when using the Vari-Stem plug. Unlike an inflatable plug that is destroyed within milliseconds of the first pressure wave, the Vari-Stem plug (when properly supported by adequate stemming material) is destroyed by the following heat wave thereby adding valuable milliseconds for the explosive gases to propagate within the rock mass and increase its destruction.

If we consider an initial deck volume of 10% (which according to the research will have little or no effect on fragmentation) that volume (34.6 litres) approximates the reduction proposed to the stemming height previously.

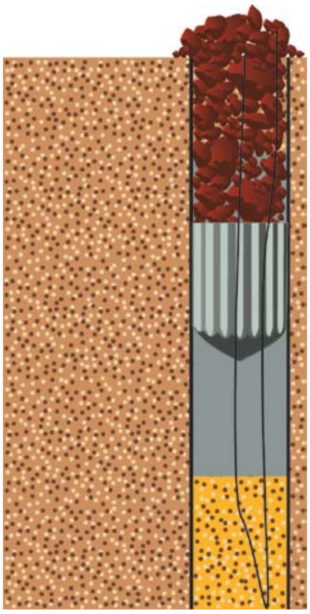

**Figure 12**: Creating a deck in the explosive column by reducing the stemming height.

Saving if 0.5m of explosive reduced in each hole:

#holes = 200 (given)
Explosive cost = US$27.00/m (given)

<u>= 200 x 27.00 x 0.5 = US$2,700 per blast.</u>

If one then considers increasing the deck to 20% air deck volume, from the graph we can see the possibility exists to reduce the explosive charge by 36kg per hole and create a 2m deck between the bottom of the plug and the surface of the explosive. If a 1.0m reduction in charge load is added to the 1.0m reduction in stemming, will deliver acceptable fragmentation (and by extension, acceptable dig & haul rates), <u>this will result in a saving of US$5,400 per blast</u> according to figures supplied (based on explosive cost of US$750 per tonne delivered):

<u>= 200 x 27.00 = US$5,400 per blast.</u>

The addition of a 1.0m inert deck lowers the powder factor/BCM to 0.24 kg/m$^3$. Given the current pattern a deck this size (and subsequent reduction in powder factor) may result in oversize. This may be left as an end target initially.

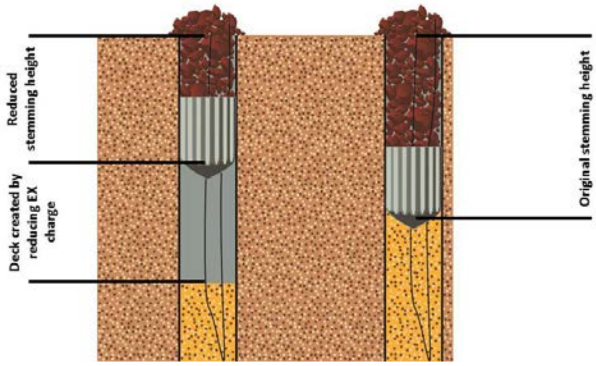


**Figure 13**: Deck created with stemming reduction, Vari-Stem plug and explosive charge reduction (NTS).

The addition of a 0.5m inert deck lowers the powder factor/BCM to 0.27 kg/m$^3$. This may prove to be a better place to start the trial process. The saving (US$13.50) per hole still exceeds the cost of the Vari-Stem plug (US$10.00) plus provides the additional benefits of:

- Consistent stemming heights contribute to consistent fragmentation.
- Provides a space above the explosive to allow expansion & can prevent dead-pressing of emulsion explosives. This improves on-bench workflow productivity.
- Plugs are proven to reduce flyrock to prevent damage to plant & equipment within the blast exclusion zone.
- Plugs are proven to reduce noise nuisance in the blast, which can be important if the blast area is in proximity to a township and there are presently community relationship issues.

**Spreading the blast pattern**

In areas of softer burden material the possibility of pattern spread appears to exist. While the burden is currently at the heuristic maximum, the spacing may be able to be expanded to the heuristic maximum of 9.2m, an increase in the spacing of 0.7m. With the explosive charge maintained at 199kg per hole (so a 1.0m deck exists due to the earlier reduction of the stemming height) the powder factor/BCM with the spread pattern is 0.27kg/m$^3$ and the blast volume increases to 147,200m$^3$ (8.2% increase). Based on the coal margin and stripping ratio given the pattern spread if successfully implemented could yield <u>a bottom-line improvement of ~US$24,000 per blast</u>:

$BV_1$ (original blast volume) = 136,000 m$^3$
$BV_2$ (expanded blast volume) = 147,200m$^3$
$MR_1$ (mass rock $BV_1$) = 350,800T
$MR_2$ (mass rock $BV_2$) = 379,776T
SR (strip ratio, given) = 12:1
$C_m$ (coal margin, given) = US$10.00/T

<u>((379,776 – 350,880) / 12) x 10.00 = $24,147</u>.

The pattern expansion is predicated on the improved containment the Vari-Stem plug can achieve in order to maintain acceptable fragmentation in the upper flitch. Given the low drilling cost per metre, reducing the number of holes drilled in the original bank (136,000m$^3$) will only deliver a modest saving (< US$3,000 per blast) compared to increasing the bank to access increased quantities of coal.

$E_p$ (pattern expansion) = 8.2% = 16 holes
$D_c$ (drilling cost/m) = US$2.73
$E_c$ (explosive cost/m) = US$27.00
$E_h$ (explosive charge/hole) = 5.5m
$B_h$ (bench height) = 11m (including sub drill)

Saving = ((2.73 x 11) + (27.00 x 5.5)) x 16
<u>Saving = US$2,856.00</u>

If the 0.5m reduction of explosive charge was possible the explosive charge reduced to 163kg per hole (so a 1.5m deck exists due to the earlier reduction of the stemming height) the powder factor/BCM with the spread pattern is 0.25kg/m$^3$. Whether this is possible or practical is a matter for discussion as part of a continuous improvement programme.

**Dig & Haul improvements**

Previous case studies on the Vari-Stem plug have discussed the effect that improved fragmentation can have on dig & haul efficiency. On understandable grounds of commercial confidence dig & haul costs were not able to be disclosed so by extension quantifying the possible tangible, commercial benefits cannot be projected here.

| Varystem digging rate | | | | | |
|---|---|---|---|---|---|
| Date | Shift | Excavator | Volume | Time (s) | Digging rate |
| 06-Aug-13 | Night | EX9010 | 1400 | 3831 | 1315.6 |
| 07-Aug-13 | Day | EX9010 | 2120 | 5098 | 1497.1 |
| 08-Aug-13 | Day | EX9010 | 8820 | 14657 | 2166.3 |
| 13-Aug-13 | Night | EX9010 | 2680 | 5172 | 1865.4 |
| 14-Aug-13 | Day | EX9010 | 1980 | 3626 | 1965.8 |

**Table 3**: Vari-Stem plug *sample* dig rate analysis

As part of the trial process we recommend historic dig rates are retrieved or tabulated so they can be compared to rates achieved in the trial area to see the extent (and cost benefit) of improvement in burden removal. It is possible to achieve percentile improvements in dig & haul rates but without trial is hard to project because of a myriad of variables such as:

- Geological variability within the pit complex,
- How well matched the digging & hauling equipment is, and machine availability, reliability & efficiency,
- Weather effects on operations (safe hauling speeds, pit access, etc.),
- Operator skill.

**Figure 14**: Truck & shovel coal mining operation.

**Summary of possible savings**

- <u>Reduction in stemming height to 4.5m:</u> no cash saving as drill cuttings are used as stemming, non-cash benefits are consistent stemming height & the effect on fragmentation in the upper flitch. Investment in the process is US$2,000 for the Vari-Stem plugs, balanced with the benefits as discussed earlier.

- Create 1.5m deck through explosive product reduction: Comprising the 1.0m stemming height reduction and a 0.5m explosive product reduction, nett cash benefit US$700 per blast after accounting for the investment in the Vari-Stem plugs.
- Create 2.0m deck through explosive product reduction: Comprising the 1.0m stemming height reduction and a 1.0m explosive product reduction nett cash benefit US$3,400 per blast after accounting for the investment in the Vari-Stem plugs.
- Spread blast pattern: Look to open pattern up especially in soft rock areas to 8m x 9.2m burden & spacing, nett cash benefit US$22,080 per blast after accounting for the investment in the Vari-Stem plugs.
- Dig & Haul improvements: to be established during the course of a future trial

**Figure 14**: Bench drilling operation.

## 9. Summary & Conclusions

From this presentation a number of conclusions may be drawn:

- Consistent stemming heights contribute to consistent fragmentation.
- Creating a deck, a gap between the surface of the explosive product and the bottom of the stemming plug, cannot only create a space for emulsion explosive to expand into (if the required gassing time was not observed for whatever reason) but an area that pressure waves may collide and create pulsations in increase micro-fractures in the rock mass. Decking is a proven technique to improve rock breakage that can be enhanced with the use of decking plugs due to the additional time to movement in the blast.
- Stemming plugs can contribute to improved fragmentation especially when used with electronic detonators or low scatter non-el dets.
- Stemming plugs can enable blast pattern expansion that can reduce drill & blast costs by up to 10%, with 3% to 5% fairly common.
- Stemming plugs can significantly increase explosive energy retention time compared to otherwise properly stemmed blast holes.
- Effectiveness of stemming plugs is inversely proportional to increase of shock energy & detonation temperature, due to faster cap disintegration.
- Improved fragmentation can be shown to debottleneck processes such as digging, hauling, material handling, crushing & milling.
- Pattern spread, where possible, can be a significant area of saving in drill & blast costs, facilitated by the energy retention capacity of the Vari-Stem plug to increase radial blast energy propagation.
- The use of plugs, combined with a higher focus on bench quality control can significantly improve blast results. Research has shown 60% of current blasting problems can be attributed to the difference between the blast design, and the design execution on the bench. The following are some common areas requiring focus: staking errors; drill set up errors; drill string wander; pre-existing cracks & voids; presence of contamination in the bottom of the hole; caved holes;

entrained water; stemming penetration; floating primers; excessive sleep time; offsets & cut-offs during the blast. Plugs add an additional step in the on-bench workflow but also add quality control points that may reduce or mitigate some of these errors.

**Figure 15**: Stemming truck in operation.

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