A newly developed plaster stemming method for blasting

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Synopsis

In this study, a newly developed plaster stemming method is studied and compared with the usual dry drill cuttings stemming method for surface blasting in mines and quarries. Drill cuttings are generally used in open pits and quarries as the most common stemming material since these are most readily available at blast sites. However, dry drill cuttings eject very easily from blastholes without offering much resistance to blast energy. The plaster stemming method has been found to be better than the drill cuttings stemming method due to increased confinement inside the hole and better utilization of blast explosive energy in the rock. The main advantage of the new stemming method is the reduction in the cost of blasting. In one series of blast tests, blasting costs per unit volume of rock were reduced to 16 per cent by increasing burden and spacing distances. Also, better fragmentation was obtained by using the plaster stemming method. Blast trials showed that plaster stemming produced finer material. In the same blast tests, +30 cm size fragments reduced to 5.4 per cent of the total, compared to 37.7 per cent in the conventional method of drill cuttings stemming. With this method of stemming, vibration and air shock values increased slightly due to more blast energy being available for rock breakage, but these increased values were small and under the permitted limit for blast damage criteria.

Keywords

plaster stemming, blasting, drill cuttings, fragmentation, limestone.

Introduction

The stemming of blasthole collars in surface mines with an inert material redirects blasting energy to the rock more efficiently, thus the energy is utilized more effectively in breaking rock. In this procedure, high efficiency of blockage is important since the blast gases should not be allowed to escape due to loose stemming material. More efficient stemming with better confinement therefore increases the generation of fines. Also, better rock breakage can be obtained. On the other hand, scatter distance is increased, giving rise to a looser muck pile that can be more easily loaded and transported.

Drill cuttings are the most common stemming material used in open pits and quarries, since they are most readily available at blast sites and are cheap. However, dry drill cuttings eject very easily from blastholes without offering much resistance to the explosion. Thus, a great percentage of blast energy is wasted and lost to the atmosphere. Cevizci[1] studied blasting parameters of open-pit blasts and obtained better results with the plaster stemming method in three different limestone quarries and one clay quarry. The new method employs a plaster prepared as a thick paste, which hardens in less than 25–30 minutes after application.

The hardened plaster creates a very strong plug, therefore the stemming column length can be reduced and the explosive column length increased. This increased explosive column results in better rock breakage than similar holes stemmed with dry drill cuttings. Also, this increased utilization of hole length reduces specific drilling costs due to increased burden and spacing distances. Blasthole drilling constitutes a major cost in blasting operations. Another advantage of the new method is better fragmentation, with more induced cracking in the rock mass.

Zhu *et al.*[2] found that strong confinement can efficiently block explosion products (gases) escaping from the borehole, thus it can intensify the extent of rock damage, which enhances the blasting efficiency. Boshoff and Webber-Youngman[3] developed a stemming performance testing rig for small-diameter boreholes, and showed that different stemming products have differences in terms of their functionality, which can have a major impact on the efficiency of rock breaking. Blasting results showed that coarse angular crushed rock is better than fine drill cuttings for

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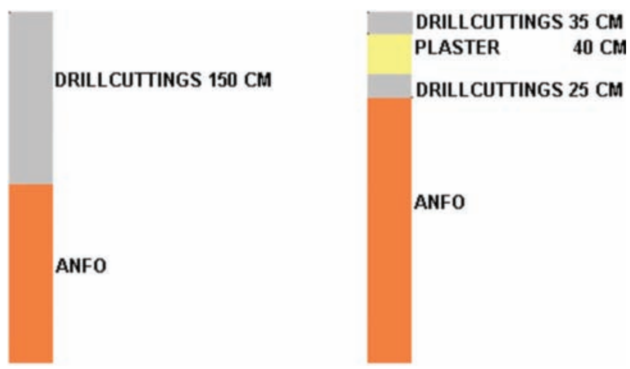
stemming (Tamrock[4]). Dobrilović *et al.*[5] studied stemming material consisting of broken limestone and found that the +16–32 mm fraction was the best-suited material. In this study, a new stemming material was investigated with the aim of increasing the blast energy directed to the rock. For this purpose, quick-setting plaster was used as a stemming material. There is no previous work citing the usage of this material. Blasting tests were carried out in quarries using both the suggested new stemming method and classical stemming material, and performance measurements carried out by image analysis of fragmented rock piles.

Method

The study was carried out at Goltas cement factory clay quarry, the Bozanonu limestone quarry of Kartas Company, and Bastas cement factory limestone quarry. A summary of the properties of materials at the blast sites, blast patterns, measurements of blast tests, and features of the bench faces is shown in Table I. Both fast-setting moulding plaster and drill cuttings were used as stemming material at different lengths in similar blastholes on the same quarry bench. A thick milky moulding plaster was prepared by mixing ten units of plaster powder and seven units of water in a barrel, and charged into the blastholes as shown in Figure 1. This wet paste hardens in 25–30 minutes. The design of the stemming, using the tests at Bozanonu limestone quarry as an example, is shown in Figure 2.

Designs of the plaster stemming at blast trials in two limestone quarries and one clay quarry are shown in Table II. Wet plaster should not be placed in contact with ANFO, which is water-sensitive, thus 25 cm of drill cuttings were placed between the explosive and the plaster paste. The top 25–55 cm of the drill hole should not be filled with plaster, since this section of the collar is deformed and cracked during drilling (Figure 3). No benefit is expected from filling this section with plaster, and it was therefore it filled with dry drill cuttings after the plaster had hardened instead of leaving it empty. This had the advantage of protecting the hole from loose stones dropping in.

Figure 1—Application of plaster paste to hole collar



(a) Stemming with drill cuttings (b) Stemming with plaster

Figure 2—Blast hole stemming at Bozanonu limestone quarry

Table I

Summary of properties of materials at blast sites, blast patterns, and measurements of blast tests

Blast Tests	Dip direction/ angle of dip / angle of blast direction relative to dip direction of discontinuity	Block size index (cm)	RQD (%)	Stemming length (m)	Bench height (m)	Average burden (m)	Average spacing (m)	+ 30 cm size fraction (%)	Delay (surface/ bottom)	Specific charge (kg/m³)	Specific drilling (m/m³)
Goltas clay (drill cuttings stemming)	210/50/30	24	70	1.9	3.6	2.8	2.9	22.9	42/500	0.39	0.14
Goltas clay (plaster stemming)	210/50/30	24	70	1.2	3.6	2.8	2.9	8.3	42/500	1.07	0.14
Bozanonu (drill cuttings stemming)	150/85/120	52	75	1.5	12.5	2.5	2.7	37.7	42/500	0.84	0.18
Bozanonu (plaster stemming)	150/85/120	52	75	1	12.5	2.7	3	5.4	42/500	0.72	0.15
Bastas (drill cuttings stemming)	225/40/225	52	65	3.5	12	2.3	2.5	46.8	9/500	1.0	0.21
Bastas (plaster stemming)	225/40/225	52	65	1.25	12	2.4	2.65	30.6	9/500	1.13	0.20

Figure 3—Cracked hole collar and hardened plaster

Blast trials and results

Muck pile fragmentation was evaluated using Split Desktop image-analysis software. The test site quarries utilize blastholes with different diameters, the rock type being limestone in two localities and clay in the other (Table II).

Goltas cement factory clay quarry

Two test blasts were carried out at Goltas cement factory clay quarry. The holes were drilled in three rows. The first round was carried out using drill cuttings stemming with 41 holes. The length of the stemming was 1.9 m. The second round was carried out by plaster stemming with 12 holes. The length of the stemming was 1.2 m.

Each blasthole was filled with 13.5 kg ANFO initiated with one primer with 0.625 kg in weight in the case of the drill cuttings stemming method. For the plaster stemming method, the quantity of ANFO was 20.5 kg per blasthole. The total length of ANFO column in the plaster stemming method was 70 cm greater than for the conventional method of drill cuttings stemming.

A total of 53 primers were used in 53 holes in both blast rounds. The blasts were initiated with detonation from the bottom of the hole. Nonel cap delays with Nonel tubes were used at the top and bottom of the holes, with 42 ms delay at the top and and 500 ms at the bottom. The rock piles from the blasting tests at Goltas cement factory clay quarry are shown in Figure 4 and Figure 5. The scales the two photographs are equal, as shown by the average size of the red balls. It can be seen from the photographs that the plaster stemming method provides better fragmentation. The cumulative percentage of retained size at the Goltas cement factory clay quarry blasting tests is given in Table III.

Figure 4—Rock pile from blast round with drill cuttings stemming at Goltas clay quarry

Figure 5 –Rock pile from blast round with plaster stemming at Goltas clay quarry

Table II

Design of plaster stemming applications

Name of quarry	Hole diameter (mm)	Section	Distance (cm)
Clay quarry of Goltas cement factory	127	Drill cuttings (at the top of the hole)	25
		Plaster column	70
		Drill cuttings (between ANFO and plaster column)	25
Bozanonu limestone quarry of Kartaş Co.	89	Drill cuttings (at the top of the hole)	35
		Plaster column	40
		Drill cuttings (between ANFO and plaster column)	25
Limestone quarry of Bastas cement factory	102	Drill cuttings (at the top of the hole)	55
		Plaster column	45
		Drill cuttings (between ANFO and plaster column)	25

Table III

Comparison of cumulative percentage of retained size (oversize) from blast trials with plaster stemming and drill cuttings stemming at the three test sites

Fragment size (cm)	Goltas cement factory clay quarry (%)		Bozanonu limestone quarry of Kartaş Co. (%)		Bastas cement factory limestone quarry (%)	
	Drill cuttings stemming	Plaster stemming	Drill cuttings stemming	Plaster stemming	Drill cuttings stemming	Plaster stemming
200	0.0	0.0	0	0	2.1	0.0
150	0.0	0.0	0	0	9.4	0.0
100	0.0	0.0	0.1	0.0	18.8	0.3
70	0.8	0.0	2.0	0.0	26.1	5.3
50	5.7	0.2	10.7	0.0	34.4	14.7
40	11.9	1.9	21.5	0.5	40.0	22.1
30	22.9	8.3	37.7	5.4	46.8	30.6
20	38.2	27.9	57.0	20.3	55.0	39.0
15	47.2	42.2	66.7	32.3	59.0	44.7
10	56.7	56.8	76.9	47.1	64.5	51.9
5	69.6	74.1	87.7	63.7	72.2	62.1

Table IV

Comparison of blasting cost of plaster stemming versus drill cuttings stemming at the three test sites

Cost item	Goltas clay quarry ($)		Bozanonu limestone quarry ($)		Bastas limestone quarry ($)	
	Drill cuttings stemming	Plaster stemming	Drill cuttings stemming	Plaster stemming	Drill cuttings stemming	Plaster stemming
ANFO	473.6	201.3	342.4	357.5	346.48	362.42
Nonel caps (surface+bottom)	274.6	80.4	46.89	46.89	46.89	40.19
Initiating electrical cap	0.5	0.5	0.5	0.5	0.5	0.5
Dynamite	162.2	47.5	27.7	27.7	11.13	9.54
Plaster and labour cost	-	10.1	-	2.7	-	2.68
Drilling cost	1731.3	506.7	996.7	996.7	947.43	812.08
Unit cost ($/m^3)	2.33	2.54	2.82	2.36	3.29	3.22
Specific charge (kg/m^3)	0.39	1.07	0.84	0.72	1.0	1.13
Specific drilling (m/m^3)	0.14	0.14	0.18	0.15	0.21	0.20

Evaluation of the blast trials

The blasted area was 316 m^2 for the drill cuttings stemming trial, and blasted volume was 1136 m^3 *in situ*. The specific charge was found to be 0.39 kg/m^3 and the specific drilling was 0.14 m/m^3. The blasted area was 92 m^2 for the plaster stemming blast trial and the blasted volume was 333 m^3 *in situ*. The specific charge was 1.07 kg/m^3 and the specific drilling was 0.14 m/m^3.

The cost per cubic metre excavated was $0.21 higher with the plaster stemming method (Table IV). However, better fragmentation was obtained, with the fraction of +30 cm size material dropping from 22.9 per cent to 8.3 per cent. This has benefits in downstream crushing and grinding. At the top level bench, small quantities of fly rock were generated, but this did not create a major problem. In addition, the plaster stemming round gave a slightly more scattered muck pile due to the greater amount of blast energy directed to the rock. Loading of the muck pile was easier owing to the looser particles.

Bozanonu limestone quarry

Two blast rounds five metres apart were carried out with the plaster stemming and with the classic conventional drill cuttings stemming, each consisting of one row of seven holes. The length of stemming was 1.5 m. In the case of the drill cuttings stemming method; each blasthole was charged with 58.7 kg ANFO and detonation initiated with two primers 0.625 kg in weight. With the plaster stemming, the spacing of the holes and burdens was increased by 10 per cent, and the quantity of ANFO was 61.3 kg per blasthole. The ANFO column in the plaster stemming method was 0.5 m longer than for the blast with the conventional method of drill cuttings stemming.

A total of 28 primers were used in 14 holes in both blast rounds. Detonation was initiated from the bottom of the holes. An extra 0.625 kg of dynamite was also used without a cap in the middle of the ANFO column to ensure the success of blasting. Nonel cap delays were used with Nonel tubes, with a delay of 42 ms at the surface and 500 ms at the bottom of the hole. The rock piles from the Bozanonu limestone quarry blasting tests are shown in Figure 6 and Figure 7. Vibration and air noise levels for both stemming methods were measured with an Instantel Minimate Blaster placed 88 m away from the blastholes. . The cumulative percentage weight retained oversize for the Bozanonu blasting tests is given in Table III.

Evaluation of the blast trials

The blasted area was 40.06 m^2 for the drill cuttings stemming trial, and the blasted volume was 501 m^3 *in situ*. The specific charge was found to be 0.84 kg/m^3 and the specific drilling was 0.18 m/m^3. The blasted area was 48.49 m^2 for the plaster stemming test, yielding a blasted volume of 606 m^3 *in situ*. The specific charge was 0.72 kg/m^3, and specific drilling 0.15 m/m^3.

The total length of holes for the plaster stemming trial at Bozanonu limestone quarry was 18.2 m less than for the drill cuttings stemming round. This resulted in 20 per cent less drilling per unit volume rock. The cost saving for drilling calculated was \$197 (18.2 m × \$10.8 per metre). At this site, specific drilling and specific charge decreased because a larger burden and spacing were applied with the plaster

Figure 6—Rock pile of blast round with drill cuttings stemming at Bozanonu limestone quarry

Figure 7—Rock pile of blast round with plaster stemming at Bozanonu limestone quarry

stemming method. In order to fragment the same volume of rock as for the plaster stemming round, an additional hole length of 18.2 m should be drilled for the drill cuttings stemming round. The cost per unit volume was $0.46 and total cost by using plaster stemming was $279 (Table IV). Therefore, the plaster stemming trial was found to be more economic as well as giving better fragmentation. For instance, the +30 cm size fraction dropped from 37.7 per cent to 5.4 per cent. This gave 86 per cent less +30 cm material. Therefore, better fragmentation is obtained with $279 profit. Also, the amount of -10 cm size material was increased from 23.1 per cent to 52.9 per cent.

Peak particle velocity (PPV) is known to be a function of site conditions (i.e. geological conditions) and scaled distance, $SD = D/W^{1/2}$, for surface blasting; where D is the distance from the blast face to the vibration monitoring point and W is weight of explosive per delay (Kuzu[6]).

Therefore, in the plaster stemming method, 61.3 kg explosive per delay was used compared to 58.7 kg in the drill cuttings stemming. This increase in explosive charge caused an increase in PPV value from 12.0 mm/s to 17.8 mm/s, whereas it should cause only a 0.4 mm/s increase in PPV value according to calculation from the theoretical formula (see Figure 8 and Figure 9). In addition, air shock increased from 132.0 dB to 132.9 dB (see Figure 8 and Figure 9). The vibration and air shock values measured at the Bozanonu limestone quarry test trials with both the drill cuttings stemming and the plaster stemming were under the safety limits specified in the limit criterion. At the top level bench, small quantities of fly rock were generated, but this did not constitute a major problem. In addition, the plaster stemming round resulted in a slightly more scattered muck pile owing to more blast energy directed to the rock, but this did not create a big problem either. Loading of the muck pile was easier due to the looser particles.

Bastas cement factory limestone quarry

Two test blasts were carried out at Bastas cement factory limestone quarry. The holes were drilled in two rows. The first round was carried out using drill cuttings stemming with 7 holes, in which the length of stemming was 3.5 m. The second round was carried out by plaster stemming with 6 holes, in which the length of stemming was 1.25 m.

Each blasthole was charged with 59 kg ANFO, initiated with primer with 0.5 kg in weight in the case of the drill cuttings stemming method. In the plaster stemming method, the quantity of ANFO was 72 kg per blasthole. The total length of the ANFO column in the plaster stemming method was 2.25 m greater than in conventional method using drill cuttings.

A total of 13 primers were used in 13 holes in both blast rounds. Detonation was initiated from the bottom of the holes. Nonel cap delays were used with Nonel tubes, with 9 ms delay at the surface and 500 ms delay at the bottom of

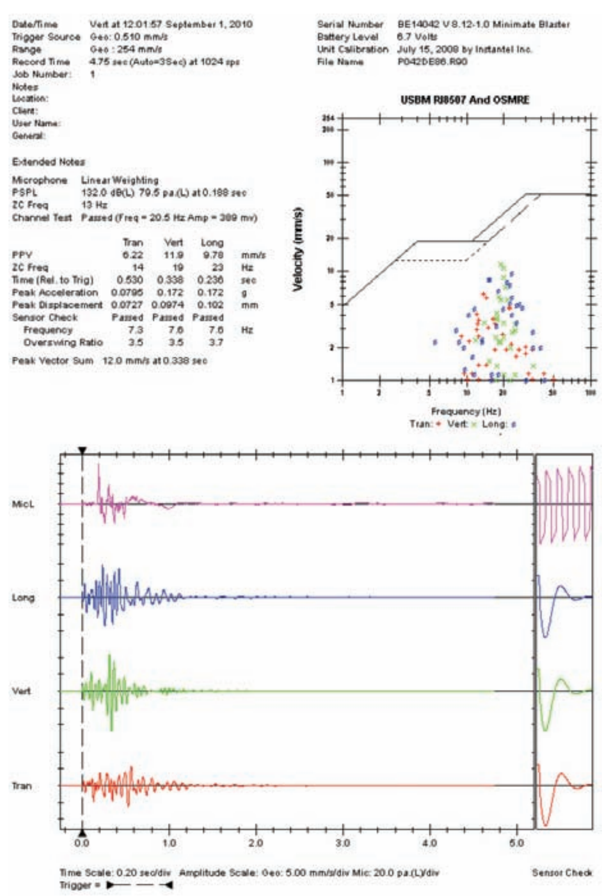


Figure 8—Measured vibration and noise levels in the drill cuttings stemming test at Bozanonu limestone quarry

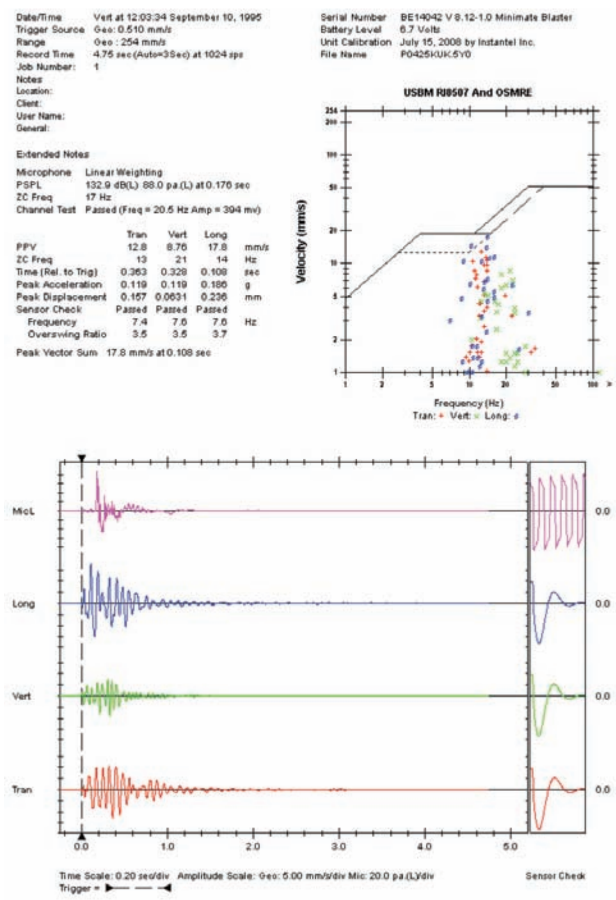


Figure 9—Measured vibration and noise levels in the plaster stemming test at Bozanonu limestone quarry

Figure 10—Rock pile of blast round with drill cuttings stemming at Bastas limestone quarry

Figure 11—Rock pile of blast round with plaster stemming at Bastas limestone quarry

the hole. The rock piles from the Bastas cement factory limestone quarry blasting tests are shown in Figure 6 and Figure 7. The cumulative weight percentage retained oversize for the tests is given in Table III.

Evaluation of the blast trials

The blasted area was 34.3 m^2 for the drill cuttings stemming trial, and the blasted volume was 411.6 m^3 *in situ*. The specific charge was found to be 1.0 kg/m^3, and the specific drilling was 0.21 m/m^3. The blasted area was 31.7 m^2 for the plaster stemming blast trial, yielding a blasted volume of 380.9 m^3 *in situ*. The specific charge was 1.13 kg/m^3 and the specific drilling was 0.2 m/m^3.

The total length of holes for the plaster stemming trial at Bastas cement factory limestone quarry was 3.9 m shorter than for the drill cuttings stemming round for whole obtained rock, resulting in 5 per cent less drilling for the plaster stemming round. Therefore, the plaster stemming method provided a lower drilling cost but a higher blasting cost per unit volume. At this site, specific drilling decreased but specific charge increased because a larger burden and spacing were applied with the plaster stemming method. In order to fragment the same volume of rock as the plaster stemming round, an additional hole length of 3.9 m should be drilled for the drill cuttings stemming round. However, the specific charge was increased. The profit per unit volume was $0.07, and total profit using plaster stemming was $26.7. On the other hand, the plaster stemming trial was found to give better fragmentation. For instance, the fraction of +30 cm size material decreased from 46.8 per cent to 30.6 per cent. With the plaster stemming round, no fly rock was generated at the top level bench, similar to the drill cuttings stemming round test trial. Also, the scattering of the muck pile with the plaster stemming round was similar to scattering of the drill cuttings stemming round.

Conclusions

In the method presented in this study, the inefficiency of the drill cuttings method of stemming is overcome using plaster stemming. With the old method of stemming, the high-pressure stress produced by blasting is not effectively confined by loosely placed drill cuttings. The study clearly shows how blasting energy is wasted by gases escaping from the drill hole without efficient confinement. With the plaster stemming method, the pressure of the explosive is used successfully due to the more efficient confinement of the blast.

Blasting experiments carried out *in situ* proved the supposition that the plaster stemming results in better confinement in blastholes, especially in short holes, where the explosive column length is short giving a lower explosive charge. In such cases, the plaster stemming method offers great benefits in breaking rock more effectively.

The measured PPV and air shock values were higher than the drill cuttings stemming method, proving that less exhaust fumes escaped to the atmosphere via the collar of the hole. The initial shock waves generated by better confinement with the plaster stemming trials are responsible for this increased efficiency of blast energy used in rock breakage.

Stemming heights were 0.5 m to 2.25 m greater in the old drill cuttings stemming method than with the plaster stemming method. These long stemming columns caused problems in blasting, since the upper collar region was not broken properly, creating large boulders (Cevizci and Ozkahraman[7]). This region, called the hard cap rock region, is not effectively broken with the classic drill cuttings stemming method. Generally, as the stemming column increases in length, the more boulders are produced, which are dangerous and costly to move.

Additionally, the new method offers a more profitable solution. The cost of drilling for one metre of hole length is almost $10.8. With plaster stemming, more of the hole length is better utilized by increasing the loaded length of hole, resulting in better breakage at the hole collar. The increased length of loading in the hard cap rock region improves the cap rock breakage, thus reducing the creation of oversized boulders and increasing both efficiency and profit. It was observed that a plaster stemming column 0.45 m in length provided a more robust sealing than 2.5 m of drill cuttings used in the classical method.

The energy utilization rate increased with the plaster stemming method by creating effective confinement with better clogging. Also, better fragmentation, increased vibration levels, fly rock, and air shock levels are all indicators of the increase in energy usage.

Carrying out the plaster stemming in the field does not take a lot of time and is not difficult or expensive. At present, hand loading is used. We are developing a machine for preparing the plaster solution that incorporates a charging unit.

It was noted that a plaster length of more than 50 cm increases the hardening time, creating a disadvantage (Cevizci and Ozkahraman[8]).The length of plaster column should range from 30 cm to 50 cm. On the other hand, in plaster stemming, if the total length of stemming including the top and bottom drill cuttings is more than 100 cm, the muck pile scatter distance is the same as for the drill cuttings stemming. It is found that total length of the plaster stemming method should be 125 cm–150 cm; if it exceeds 150 cm muck pile fragmentation becomes worse.

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