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Achieving higher pull and yield in solid blasting in underground coal mines using spacer-aided-initiation technique

Spacer-aided-initiation technique envisages distribution of explosive energy over longer length of shot hole using plastic spacers for air decking of cartridges with single priming at one end of suitable P_5 explosives for achieving longer pull in solid blasting. In a Ministry of Coal funded S&T project, all relevant parameters were studied by Explosive and Explosion Laboratory of CIMFR under simulated conditions to establish safety and efficacy of using spacer-aided-initiation technique in solid blasting in underground coal mines. Based on which, DGMS approved this method initially for field trial in May 2007 and after successful field trial finally for commercial use in August 2009. A special P_5 explosive having high air gap sensitivity namely Pentadyne-HP was also developed for use in this method.

Pull up to 1.7m in shot holes of 1.8m length and up to 2.2m in shot holes of 2.4m length were achieved with yield of coal ranging from 24 to 41 tonnes per blast depending on the face dimensions during field trial of this method with Pentadyne-HP in an underground coal mine of SCCL. Considering the fact that there has not been any innovation in solid blasting since its inception in 1969, improvement in pull and yield by 60% to 110% under different conditions achieved using spacer-aided-initiation in solid blasting with Pentadyne-HP can be considered to be a great achievement. Result of field trials proved that this method of spacer-aided-initiation has potential to increase production and productivity of underground coal mines in India by achieving consistently higher pull and yield per blast in solid blasting.

Introduction

Coal production from underground mines in India has been stagnating over last three decades in spite of various efforts made by the concerned authorities. As the production from the opencast mines is likely to reach its plateau in coming years, production from underground coal mines has to be increased for sustainable growth of Indian coal mining industry. The bord and pillar method is the predominant underground coal mining system in India, contributing about 95% of the total underground coal production. Solid blasting (or blasting off-the-solid) of coal in underground mines in India started in 1969 after the development of suitable P_5 explosives and non-incendive short delay detonators. Solid blasting got wider acceptability due to its various advantages and gradually replaced the coal cutting machines needed to give cuts prior to blasting with P_1 or P_3 explosives. Nowadays, solid blasting is the predominant method of blasting in driving galleries in underground coal mines. Solid blasting using P_5 explosives in production faces during drivage of in-seam galleries in bord and pillar method contributes about 60% of underground coal production in India [1]. There has not been any innovation in solid blasting in last four decades for improving pull and yield per blast.

P_5 explosives being the weakest of all permitted explosives, alongwith limitation on its maximum charge weight per holes, solid blasting in Indian underground coal mines has always suffered from low productivity. An average pull (i.e. advancement of face per round of blasting) of 1.0 - 1.2 m and yield of 12 - 18 tonnes per blast in solid blasting with gallery dimensions of 3.5 - 4.5m width and 2.0 – 3.0m height in different geo-mining conditions following common blasting patterns of wedge cut, fan cut etc. have never been considered satisfactory for optimum utilisation of men and machines at faces and more so with introduction of semi-mechanization in most of the underground coal mines [2]. It has been a great challenge for the Indian coal mining industry to increase the availability of coal at the faces to increase the utilization factor and productivity of SDL and LHD machines introduced in large numbers in recent past.

Spacer-aided-initiation technique described in the paper is an effort by the authors to increase the availability of coal at the face by increasing pull per blast by innovation in application of suitable permitted explosives in solid blasting in underground coal mines. This paper describes the concept of spacer-aided-initiation technique and how apprehensions of likely unsafe situations with this technique was removed under a Ministry of Coal Funded S&T project [3] which enabled DGMS to approve this technique for its application in underground coal mines. Comparison of performance of

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conventional solid blasting with spacer-aided-initiation technique in solid blasting in an underground coal mine of SCCL has also been presented in the paper to prove its advantages.

Spacer-aided-initiation technique in solid blasting

Explosive and Explosion Laboratory of CIMFR conceived and filed a patent through CSIR in India on a method of solid blasting in underground coal mines using spacer-aided-initiation technique for achieving longer pull. This method of spacer-aided-initiation in solid blasting envisages distribution of explosive energy over longer length of shot hole using plastic spacers for air decking of cartridges of suitable P_5 explosives with single priming at one end for achieving longer pull as shown in Fig.1.

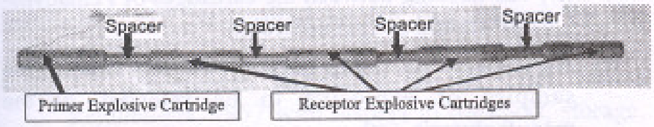

Fig.1 Concept of spacer-aided-initiation in solid blasting in underground coal mines

Whereas separate initiation for each deck of explosive columns or a device useful for transmission of detonation from one deck to other (e.g. detonating cord) are used in conventional air decking being practiced for long in opencast blasting or tunnelling, in spacer-aided-initiation technique single initiation at one end is used. Spacer-aide-initiation technique utilizes the inherent air gap sensitivity of suitable P_5 explosive to distribute the explosive energy over longer length for achieving higher pull in solid blasting. Therefore, spacer-aided-initiation technique is different from conventional air decking. In this technique, receptor cartridges get initiated sympathetically from the explosion energy emanated by the previous cartridge. Ability of an explosive to initiate other cartridge at a distance reduces drastically if either gap between the cartridges are increased or the gap is filled with inert material. In order to maintain the distance between the cartridges as well as stopping intrusion of inert material (e.g. coal dust) between the cartridges when loaded into the shot hole, high density polyethylene (HDPE) spacers, similar to that used in blasting gallery method as shown in Fig.1, are used. As these spacers aids in initiation of receptor cartridges this technique has been termed as "spacer-aided-initiation" technique.

Rock blasting with air-decking of explosive charges has a long history, the earliest reference regarding the advantages of air decking in production blasts dates as far back as 1893 to the work of Knox as reported by Liu and Katsabanis [7]. Many researchers have applied air decking in pre-splitting, controlling ground vibrations and fly rocks, reducing fines, improving powder factor, fragmentation and blast economics in opencast mines and in tunnelling [8-13]. But, so far air decking was not approved in solid blasting in underground coal mining because of risks associated with use of multiple initiations in single hole or use of detonating cord. Use of air decking in Indian underground coal mines is approved only in ringhole blasting in blasting gallery method with non-incendive low grammage detonating cord.

Considering success of air decking of explosives in improving blast performance in opencast mining and tunnelling, spacer-aided-initiation technique in longer holes in solid blasting was expected to increase the pull and yield per blast provided unfailing detonation of receptor cartridges was ensured by suitably selecting the explosive and length of the air decks. Length of the air decks should not exceed the maximum distance over which the detonation wave from a primed cartridge can jump to the receptor cartridges under practical usage conditions. Failure of transmission of detonation wave from the primed cartridge to the subsequent ones in a blast hole may cause misfire of the receptor cartridges. Misfired cartridges under the action of heat and pressure generated by the detonation of other cartridges in same or adjacent holes can lead to their deflagration, which can be a grave hazard in underground coal mines. Use of spacers for providing air gaps between the cartridges should not add significantly to post detonation toxic fumes generated by the explosives so as to exceed the permissible limits. Therefore, misfire, deflagration and increase in post detonation fumes were apprehended hazards of using CIMFR's patented method of spacer-aided-initiation in solid blasting in underground coal mines [2]. DGMS advised CIMFR to generate sufficient data under simulated conditions before this method can be approved for use in underground coal mines.

Under a Ministry of Coal funded S&T project titled "Optimisation of production from blasting off-the-solid (BOS) by achieving longer pull (Phase-I)", Explosive and Explosion Laboratory of CIMFR studied all relevant parameters under simulated conditions in the laboratory and in an opencast mines of SCCL to establish safety and efficacy of using this method of spacer-aided-initiation technique in solid blasting in underground coal mines [3].

The results of studies of S&T project revealed that with proper selection of explosive and air decking length, any apprehension of misfire, deflagration and adverse effect on toxic fume quality due to use of spacer-aided-initiation technique in solid blasting can be eliminated. Thus this technique of spacer-aided-initiation technique in solid blasting using suitable P_5 explosive with high density polyethylene (HDPE) spacers can be tried for improving blast performance in underground coal mines [2, 3].

Under this S&T project Explosive and Explosion Laboratory of CIMFR guided Gulf Oil Corporation Limited for development of a new P_5 explosive Pentadyne-HP (code no.: PE-5U) which was found to be suitable for use in spacer-aided-initiation technique in solid blasting with gap up to

15cm using HDPE spacers of not more than 21g weight. Some of the characteristics of Pentadyne-HP explosives are given in Table 1. VOD graph of five cartridges of Pentadyne-HP explosives air decked using four HDPE spacers as arranged in Fig.1 has been shown in Fig.2.

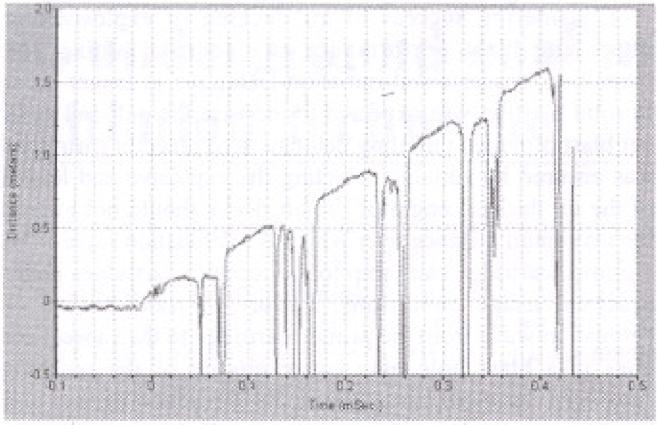

Fig.2: VOD graph of Pentadyne-HP cartridges spaced with HDPE spacer of 16cm effective air gap length

Based on the results of studies conducted by CIMFR under the S&T project, DGMS approved vide letter no. S66021/196/2006-Genl/2551 dated 30.05.2007 use of Pentadyne-HP (composition PE-5U) for the purpose of conducting field trials in belowground workings of gassy coal mines/seams of first degree for the blasting coal off the solid for larger pull subject to the following conditions:

1. (a) The composition and characteristics of the explosive shall at all times, conform to those of the Sample-A (i.e. Pentadyne-HP with code no. PE-5U) officially tested at CIMFR, Dhanbad as revealed in the CIMFR report dated 07.04.2006 bearing patent filed no.1538DEL2005.

   In order to ensure this, strict control shall be exercised on the quality of manufacture and such periodic inspections and tests, including repeat incendivity tests, shall be carried out and such records shall be maintained as may be necessary.

   (b) (i) Manufacturer should maintain strict quality control on ingredients, processes and final products during manufacture of Pentadyne-HP explosive with code no. PE-5U.

   (ii) Every batch of Pentadyne-HP explosive should be checked for AGS, COD, VOD, density and important chemical ingredients by the manufacturer.

   (iii) Air decking should be provided with HDPE spacers of the quality used in BG panels and average weight of HDPE spacers should not exceed 21 g.

   (iv) Air decking between the cartridges of Pentadyne-HP should not exceed 15cm.

   (c) An inspector of mines may also, at any time, cause samples of explosive to be retested, at the manufacturer's cost.

2. (a) Concurrence from the management of mines to allow field trials shall be conveyed to this Directorate. Trial shall be carried out in at least two mines of different coal fields.

   (b) Before commencement of trial at a colliery, this Directorate as well as the concerned Dy. Director General of Mines Safety/Director of Mines Safety shall be informed in advance. At least two blasts shall be conducted in the presence of an officer of this Directorate who will submit separate report to this Directorate.

   (c) The shelf life of the explosives shall be intimated to the mine management and this Directorate.

   (d) The explosive of the same batch shall be tested for air-gap sensitivity at an interval of 2, 4 and 6 months at CIMFR, Dhanbad and the report shall be submitted.

TABLE 1: CHARACTERISTICS OF PENTADYNE-HP EXPLOSIVE

1	Name of explosive	:	Pentadyne-HP
2	Type of explosive	:	Slurry
3	Weight of a cartridge	:	200 g
4	Permitted group	:	P_5
5	Air gap sensitivity in open unconfined condition	:	16 cm
6	Continuity of detonation in open as per IS 6609 (Part II/Sec 2)	:	Passed
7	Continuity of detonation with multiple HDPE spacer in open unconfined condition	:	Passed with HDPE spacer of 16 cm effective air gap length
8	Continuity of detonation with multiple HDPE spacer in coal bed confinement in a opencast mine	:	Passed with HDPE spacer of 20 cm effective air gap length
9	Post detonation fumes under statutory conditions	:	Within the statutory limits
10	Velocity of detonation	:	3783 m/s
11	Relative weight strength	:	1%
12	Shelf life	:	More than 6 months with 15cm air gap sensitivity in open

(e) The studies of the deflagration property of the above composition shall be carried out and the results shall be submitted. If the sample fails in the deflagration tests, the approval shall be deemed to have been suspended.

(f) The trials shall be completed within six months from the date of issue of this letter. This was later extended for another six months up to 30.05.2008 vide letter no. S66021/196/2006-Genl/1861 dated 09.01.2008.

3. Field-trials shall be carried out under the direct supervision of the officers of the Technical Services of Gulf Oil Corporation Limited, Hyderabad and CIMFR, Dhanbad and a detailed report on these field-trials shall be submitted to this Directorate in Form-I along with the blast details of each blast after the trials are over. Minimum 1000 kg of the explosive shall be used during the trial. The mine official shall be trained to use this system by the manufacturer.

4. (a) All precautions stipulated in the Coal Mines Regulations, 1957 with respect to transport, storage, handling, charging and firing of permitted explosive in below-ground workings of coal mines shall be strictly complied with.

(b) At the colliery selected for trials, ventilation shall be adequate enough to ensure at least 284 cubic meters of air per minute at the ventilation connection out-bye of every face where this explosive is to be used.

(c) Tests for inflammable gas shall be made at and within a radius of 20 meters of the place of firing with an approved type of methanometer and no shot shall be fired if 0.1% or more inflammable gas is found at any place in the said zone.

(d) The ventilation shall also be adequate to ensure dilution of carbon monoxide and oxides of nitrogen in blasting fumes to less than 50 parts per million (ppm) and 5 parts per million (ppm) respectively within a period of 5 minutes. In addition, no person shall be allowed to re-enter the place where blasting operation has been done with these explosives unless blasting fumes are cleared and unless a period of at least 15 minutes has elapsed from the time of blasting.

5. The permissible maximum charge of Pentadyne-HP in a shot-hole shall not exceed 1000 g.

6. Please note that

(a) If at any time, anyone of the conditions subject to which this approval has been granted is not complied with, this approval shall be deemed to have been revoked with immediate effect.

(b) This approval may be amended or withdrawn, at any time if considered necessary in the interest of safety.

(c) This is being issued without prejudice to any other provision of law that may be or become applicable at any time

7. Subject to the above conditions, this permission shall remain valid so long as the said explosive is of the type authorized and duly classified by the Chief Controller of Explosives.

Thus, DGMS approved for the first time use of spacer-aided-initiation technique in solid blasting with Pentadyne-HP explosive in underground coal mines for achieving longer pull.

Field trial of spacer-aided-initiation technique in solid blasting

In consultation with SCCL management, Godavarikhani No. 5 (GDK-5) incline of Ramagundam Area-1 was selected for the field trial of Pentadyne-HP explosive with spacer-aided-initiation technique in solid blasting. GDK-5 incline is one of the highly mechanized underground coal mines of SCCL. GDK-5 incline falls in South Godavari Coalfields of SCCL and is located between latitude North 18°44'33" and longitude East 79°31'17". The general direction and full dip of the seams is N 56°23'28" E and 1 in 5.5 respectively. This mine is surrounded by GDK. No. 2 and 2A incline on north side, GDK. No. 6 incline on south side, Mustyala village on east side and Sector-II township on the west side. There are two major faults, one on north side having about 20 m up-throw between GDK-5 incline and GDK-2 incline and the other on south side having about 100 m down throw between GDK-5 incline and GDK-6 incline.

The area has five workable seams namely 1, 2, 3A, 3 and 4 seams in descending order. All the seams fall under south Godavari coalfield under Barakar series. Nos. 1 and 2 seams are being worked by the adjoining mine GDK-5A incline and No. 3A, 3 and 4 seams are being worked by GDK-5 incline. Both mines are not connected with each other. Both the mines are under one Agent. Access to No. 4 seam was made through two pairs of tunnels namely GDK-5 incline and GDK-4 incline with a gradient of 1 in 7 and 1 in 6 respectively. Salient points about the mine are:

Area of the mine	:	495.57 hectares
Mine lease hold area	:	475.32 hectares
Geological reserves	:	64.91 million tonnes
Extractable reserves	:	31.99 million tonnes
Remaining extractable reserves	:	20.75 million tonnes

TABLE *

Seam	Thickness	Partition	Minimum depth	Maximum depth	RMR value	Grade	Overall grade
3A	1.5m - 2.5m	–	30m	263m	62	'D'	
3	7.0m - 8.0m	12.0m	25m	330m	54	'C'	'C'
4	3.3m - 4.0m	12.0m	19m	337m	57	'C'	

No. 3A seam, being the upper most seam of GDK-5 incline, was completely developed and depillared on north side of the property. Development was to be undertaken in the south side towards dip direction in No. 3A seam. No. 3 seam was having a thickness of 7.0 m to 8.0 m. It was developed along stone floor with 2.5 m height. Partition between 3A and 3 seam bottom section was 6.0 m. This seam was also completely developed. Three LHDs were working in 3S/20 panel by caving. No. 4 seam was having a thickness of 4.0 m. Development had been done along floor on south side and along roof on north side, to an average height of 2.7m. Partition between 3 seam and 4 seam was 12.0 m. Depillaring was being carried out with hydraulic sand stowing in panel no. 4S/21 (south). Two SDLs were working in panel No. 4S/16 and 4 SDLs were working in 4S/24 on north side during the trials in GDK-5 mine.

Field trial of spacer-aided-initiation technique in solid blasting using Pentadyne-HP explosive was conducted in development faces of No.4 seam of GDK-5 incline. Seam consists of compact coal and dark grey shale. The density of coal is 1.67g/cc and its compressive strength is 202 kg/cm^2. In development faces, width of the galleries varied from 3.4 to 3.8m and height varied from 2.4 to 2.8m.

Wedge cut pattern was being followed in solid blasting in GDK-5 incline. The existing wedge cut pattern in GDK-5 incline used 12 holes in 3 rows with 4 holes in each row. Only 4 different delay detonators with 0, 2, 4 and 6 were normally available in the mine magazine and thus were used in a round in GDK-5 incline. Holes were drilled manually using 1.8 m drill rods. Explosive used was Powergel P-501, an emulsion P_5 explosive of Indian Explosive Limited, Gomia. Each cartridge of the Powergel P-501 weighs 185 g. Depending on the location of hole, three or four cartridges of Powergel P-501 was being used in a hole. In existing practice of solid blasting, subsequent cartridges placed in a hole were touching the previous cartridge to form a continuous column of explosive cartridges. An average pull of 1.0m with yield of approximately 16 tonne, powder factor of approximately 1.88 tonne/kg and detonator factor of approximately 1.33 tonne/detonator were generally achieved with existing wedge cut solid blasting pattern in GDK-5 incline. Normally, socket of around 0.3 - 0.5 m were observed in each blast which was not only a waste of drilling length but also unsafe because accidents have happened in the past in some mines where misfired cartridges in sockets have been found to be the probable reasons for their accidental initiation during drilling for next round of blasting.

As the maximum pull in a wedge cut pattern is restricted to the effective depth of the cut holes considering their inclinations, in a wedge cut pattern with 1.8m long drill rods, the maximum pull cannot exceed 1.50 m. Nowadays, when mine managements are considering introduction of five cubic meter diesel operated LHDs in underground coal mines, a pull of even 1.5 m may not be enough for their optimum utilization and thus even higher pull of about 2.0 m needs to be achieved in coming days. Use of spacers was expected to be more effective in longer holes because it will provide distribution of the explosive energy over longer length of the hole instead of explosive cartridges just being placed at the bottom end of the hole. Moreover, drilling of inclined holes of more than 2m length is difficult within the limited width of the gallery. Therefore, trials for spacer-aided-initiation technique in solid blasting with Pentadyne-HP were carried out with parallel cut pattern in GDK-5 incline to achieve longer pull. All the holes were drilled almost parallel to each other. Initially a number of parallel cut pattern with number of holes ranging from 12 to 19 were tried. It was found that parallel cut pattern shown in Fig.3 with 16 holes gave most consistent and optimum results. As seen in Fig.3, it was initially proposed that two 100mm diameter holes at the centre (marked with E) would be drilled to be kept empty to provide some initial free space for expansion of coal during blasting. But, mechanized universal drilling machine was not operational in the mine in development faces during the trial period and it was very difficult to drill 100mm diameter holes manually. Thus, trial blasts with Pentadyne-HP with parallel cut pattern were done without empty holes. Digits like 0,1,2….,6 written near the holes in Fig.3 denote the delay number of the detonator used in that hole.

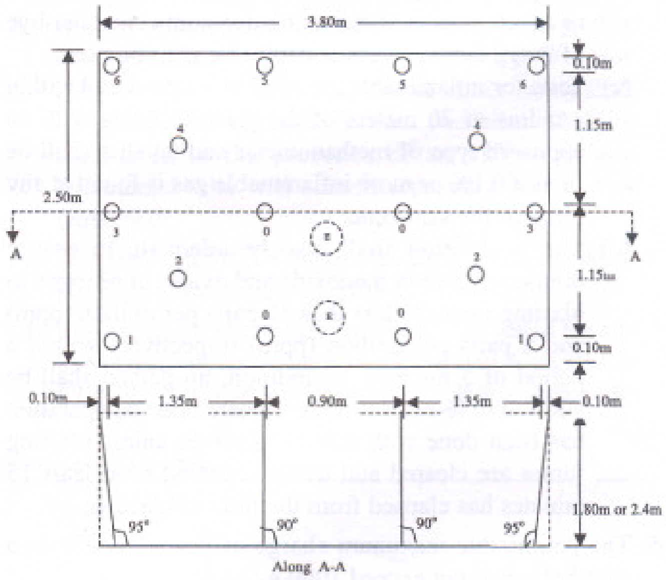

Fig.3 Parallel cut pattern tried at GDK-5 incline

Charging patterns of different holes in parallel cut pattern tried with Pentadyne-HP in GDK-5 incline are given in Table 2. In the charging pattern column of the Table 3, 'C' refers to cartridge and 'S' refers to spacer. Charging pattern of 2C + 1S + 1C + 1S + 1C+ 1S + 1C means two cartridges including one primer cartridge in contact followed by one spacer, then one cartridge followed by one more spacer and then one more cartridge follower by a spacer and one last cartridge were charged inside the hole as shown in Fig.4. Arrangements of four cartridges with three spacers have been shown in Fig.5

Table 2: Charging pattern with Pentadyne-HP in parallel cut pattern

Hole no.	Position of hole	Delay no.	No. of cartridges	No. of spacers	Charging pattern
1 - 4	Bottom and middle row, cut holes	0	5	3	2C + 1S + 1C + 1S + 1C+ 1S + 1C
5 - 6	Bottom row, corner holes	1	5	3	2C + 1S + 1C + 1S + 1C+ 1S + 1C
7 - 8	Intermediate row	2	4	3	1C + 1S + 1C + 1S + 1C+ 1S + 1C
9 - 10	Middle row, corner holes	3	4	3	1C + 1S + 1C + 1S + 1C+ 1S + 1C
11 - 12	Intermediate row	4	4	3	1C + 1S + 1C + 1S + 1C+ 1S + 1C
13 - 14	Top row, centre hole	5	4	3	1C + 1S + 1C + 1S + 1C+ 1S + 1C
15 - 16	Top row, corner holes	6	5	3	2C + 1S + 1C + 1S + 1C+ 1S + 1C

respectively. Each HDPE spacer was having 15cm effective air gap length and was of quality used in BG panels.

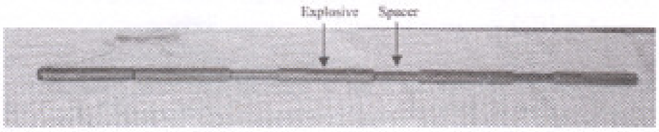

Fig.4 Arrangement of five cartridges with thee spacers

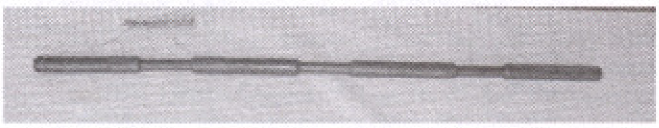

Fig.5 Arrangement of four cartridges with thee spacers

Some of the restrictions which were to be followed as per Coal Mines Regulation, 1957 while carrying out solid blasting in an underground coal mines were:

(i) only P_5 explosive to be used with approved type of permitted delay detonators

(ii) the maximum charge in a hole should not exceed 1000 g in degree I and 565 g in degree II and III mines

(iii) the total delay period not to exceed 150 ms in degree I mines and 100 ms in degree II and III mines

(iv) the adjacent holes with different delays not to be closer than 0.6 m at the explosive charged end.

Apart from above mentioned points, additional important statutory conditions imposed by the DGMS for field trial of spacer-aided-initiation technique in solid blasting using Pentadyne-HP vide permission letter no. S66021/196/2006-Genl/2551 dated 30.05.2007 were (i) air decking to be provided with HDPE spacers of the quality used in BG panels and average weight of HDPE spacers should not exceed 21g, and (ii) air decking between the cartridges of Pentadyne-HP not to exceed 15 cm. Therefore, field trial of Pentadyne-HP was carried out keeping in mind these statutory restrictions of solid blasting in GDK-5 incline.

Parallel cut pattern with Pentadyne-HP using spacer-aided-initiation technique in GDK-5 Incline were tried mostly with 1.8 m length holes. Encouraged by the result of trials with 1.8m length shot hole, five trials were also carried in parallel cut pattern with Pentadyne-HP using spacer-aided-initiation technique using 2.4 m length holes. As manual drilling of 2.4 m parallel holes was very difficult, more trials could not be done under such conditions. Around 1000 kg of Pentadyne-HP explosive was used during the trial blasts in GDK-5 incline. Comparison of blast performance achieved with the existing wedge cut pattern and with spacer-aided-initiation technique using Pentadyne-HP in parallel cut pattern has been given in Table 3.

Discussion on the results

An average pull of 1.0 m in average face dimension of 3.8 m × 2.6 m size was being achieved with the existing wedge cut pattern of solid blasting in GDK-5 incline using an emulsion type permitted P_5 explosive. Considering mechanization of loading operation using load haul dumpers (LHD), yield of coal per blast with pull of around 1.0 m was just sufficient for 8-10 round of LHD. Although, up to 1000g of explosive per hole is approved in a degree-I gassy mine, maximum 740g was being used. Mine management had observed that even with increase in number of cartridges in different holes, and thus increase in total explosive charge in a round, there was no proportionate rise in the pull and yield of coal per blast in the existing wedge cut pattern of conventional solid blasting at GDK-5 mine. In the existing conventional solid blasting at GDK-5 incline, powder factor was varying between 1.65 – 2.35 tonne/kg of explosive and detonator factor was varying from 1.16-1.67 tonne/detonator. Higher values of powder factor and detonator factor correspond to the higher gallery dimension of 4.0m × 2.8m in which maximum pull of 1.1m was achieved.

From the results of trials of spacer-aided-initiation technique using specially developed high AGS Pentadyne-HP explosive in parallel cut pattern in table 6, it can be observed that pull up to 2.2 m in 2.4 m shot holes and up to 1.70 m in 1.80 m shot holes were achieved which yielded 24 to 41 tonnes of coal per blast. Thus, average pull and yield per blast with spacer-aided-initiation technique using Pentadyne-HP explosive in parallel cut pattern was found to be about 60 to 110% higher than that with convention solid blasting being practices in GDK-5 incline. In all the five trials conducted with 2.4m shot holes, pull per blast were not less than 2.0m. As drilling of 2.4m parallel shot holes manually were very difficult, more trials were conducted with 1.8m shot holes. Even though the numbers of shot hole in a round were increased from 12 holes to 16 holes and maximum charge in a hole from

Table 3: Comparison of blasts results of spacer-aided-initiation in parallel cut pattern with existing wedge cut pattern in GDK-5 incline

	Parameters	Existing practice	Modified practice	
1	Pattern of blasting	Wedge cut	Parallel cut	Parallel cut
2	Face dimension	2.5 m × 3.8 m to 2.8 m × 4.0 m	2.5 m × 3.8 m to 2.8 m × 4.0 m	2.8 m × 4.0 m
3	Name of explosive used	Powergel P-501	Pentadyne-HP	Pentadyne-HP
4	Type of explosive	P_5	P_5 with high AGS	P_5 with high AGS
5	Weight of each cartridge	185 g	200 g	200 g
6	HDPE spacers used	No	Yes, length 15 cm	Yes, length 15 cm
7	No. of holes	12	16	16
8	Length of holes	1.8 m	1.8 m	2.4 m
9	Total charge	8.51 kg	14.40 kg	14.40 kg
10	Total number of detonators	12	16	16
11	Maximum charge per hole	740 g	1000 g	1000 g
12	Minimum charge per hole	555 g	800 g	800 g
13	Maximum charge per delay	2.96 kg	4.00 kg	4.00 kg
14	Pull per blast	0.90 to 1.10 m	1.50 to 1.70 m	2.00 to 2.20 m
15	Yield per blast	14-20 tonne	24-32 tonne	37-41 tonne
16	Powder factor	1.65-2.35 tonne/kg	1.65-2.22 tonne/kg	2.57-2.85 tonne/kg
17	Detonator factor	1.16-1.67 tonne/det	1.50-2.00 tonne/det	2.31-2.56 tonne/det
18	Sockets	0.3-0.5 m	0.0-0.3 m	0.0-0.3 m
19	CO after 5 minutes of blast	18-32 ppm	22-36 ppm	22-36 ppm
20	NO_x after 5 minutes of blast	0 to < 5 ppm	0 to <5 ppm	0 to <5 ppm

770g to 1000g, the powder factor and detonator factor increased because of increase in yield per blast.

In comparison to 0.3 - 0.5 m of sockets observed in each hole of conventional wedge cut solid blasting in GDK-5 incline, in some blast with spacer-aided-initiation technique no sockets were observed and in some blasts some holes were found to have maximum socket of 0.3m. After five minutes of blasts, carbon monoxide (CO) and oxides of nitrogen (NO_x) were found to be within the statutory limits of 50ppm and 5 ppm respectively. Although charge per delay and total charge weight per round of blasting in parallel cut pattern was higher than the earlier pattern, no adverse effect on the pillars and roof were observed. Moreover, no misfire or deflagration of any cartridge of Pentadyne-HP was observed during the field trial at GDK-5 incline in which around 1000kg explosive was used. Observing satisfactory performance of spacer-aided-initiation technique in solid blasting during the field trials, DGMS have given general approval for use of spacer-aided-initiation technique in solid blasting using Pentadyne-HP vide their letter S66021/196/2006-Genl/2949 dated 28.08.2009.

Conclusion

Studies conducted under simulated conditions in the laboratory and in a opencast mine by Explosive and Explosion Laboratory under a Ministry of Coal funded S&T proved that spacer-aided initiation technique can be safely used in solid blasting in underground coal mines for achieving higher pull with proper selection of suitable P_5 explosive. Considering the need for a P_5 explosive possessing high air gap sensitivity for use in spacer-aided initiation technique in solid blasting, CIMFR guided GOCL in development of Pentadyne-HP explosive. Pentadyne-HP explosive meets all statutory requirement of P_5 explosive and possess 15cm air gap sensitivity in open up to its shelf life of six months. On CIMFR recommendations DGMS approved field trial of Pentadyne-HP in spacer-aided-initiation technique as P_5 explosive in degree-I mines up to 1000g charge weight per hole with air gap up to 15cm using HDPE spacers of not more than 21g weight.

Average increase of pull by 60% with 1.8m shot holes and 110% with 2.4 m shot holes in GDK-5 incline of SCCL without any risk of misfire or deflagration or increase in toxic gases in post blast fumes validated the safety and efficacy of using spacer-aided initiation technique in solid blasting with newly developed Pentadyne-HP explosive. Results of experimental trials of spacer-aided initiation technique in solid blasting with parallel cut pattern proved that it was possible to consistently achieve yield of around 40 tonnes of coal from a face of 4.0m × 2.8m without endangering safety in underground coal mines. After DGMS approval for commercial use of Pentadyne-HP with spacer-aided initiation technique in August 2009, it can be applied in solid blasting in any degree-I mines for achieving higher pull and yield of coal for increasing production and productivity of underground coal mines.

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