터널과 지하공간, 한국암반공학회지 제20권 제5호, 2010년 10월, pp. 325~331
TUNNEL & UNDERGROUND SPACE, Vol. 20, No. 5, 2010, pp. 325-331
Journal of Korean Society for Rock Mechanics

Comparison of Fragmentation Performance of Two Different Blast Patterns

Piyush Rai[1)], Hyung-Sik Yang[2)]*

두 가지 발파 패턴의 파쇄 성과 비교

피유시 라이, 양형식

Abstract In the present research paper large scale blasting was conducted on two different firing patterns, namely, straight V type and skewed V type pattern on the same sandstone overburden bench with similar explosives. The post-blast fragmentation assessments were made by use of digital imaging technique. The total cycle time of 10 m^3 rope shovels was also recorded in the field. The results reveal improvements in the fragmentation and excavator performance results for the blasts fired on skewed V type pattern. The paper discusses the skewed V firing pattern and the reasons for its superior performance vis-à-vis the straight V type pattern.

Key words Firing pattern, Fragment size, Excavator performance.

초 록 이 연구에서는 사암 벤치에 대하여 V형과 경사 V형의 두 가지 기폭 패턴으로 대규모 발파를 실시하였다. 장약량은 비슷하였다. 발파 후 디지털 이미지 프로세싱 방법으로 파쇄석의 파쇄도를 평가하였다. 10 m^3 용량 로우프 쇼벨의 싸이클 시간도 계측하였다. 그 결과는 경사 V형으로 기폭한 경우 파쇄성능이나 굴착기 성과가 더 향상된다는 것을 보여준다. 이 논문에서는 경사 V형 패턴이 V 형 패턴보다 더 나은 성능을 보이는 이유에 대하여 논한다.

핵심어 기폭패턴, 파쇄입도, 굴착기 성능

1. Introduction

Fragmentation is fundamental to rock blasting and serves as a measure of blast effectiveness as it exerts cascading impact on the economics and productivity of the downstream mining operations. As such, over the years there have been significant technological advancements in the field of rock fragmentation by blasting. The traditional concepts have rapidly advanced, resulting into the emergence of newer concepts and techniques largely due to the fact that the blast design falls under the domain of controllable parameters. These parameters can be varied at field scale to evaluate their impact on fragmentation. In order to specifically assess the effect of change of blast design parameters on fragmentation, the explosive as well as rock parameters must be kept reasonably constant in order to avoid the mixing up of interpretation due to many changes at one time. Further, judicious selection and control of various blasts design parameters vis-à-vis the site specific conditions go a long way in accomplishing the goals of fragmentation.

In this light, the present research paper evaluates the influence of firing pattern on rock fragmentation in large scale, multi-row blast rounds in sandstone overburden bench of a major opencast coal mine.

[1)] 전남대학교 방문 교수, 인도 바나라스 힌두대학교 광산공학과 부교수
[2)] 전남대학교 에너지자원공학과 교수
* 교신저자 : hsyang@jnu.ac.kr
접수일 : 2010년 9월 29일
심사 완료일 : 2010년 10월 21일
게재 확정일 : 2010년 10월 25일

2. Objectives

The objectives of the present study were to implement skewed V and straight V type patterns and compare their performance at field-scale on a sandstone overburden bench. Evaluation of fragmentation results was done by using state-of-art image processing and analysis technique for quantification of the fragment size and its distribution in the blasted muck piles. Further, the influence of the firing patterns was investigated on the total cycle time of 10 m^3 rope shovels excavating the blasted muck piles.

3. Mine description

The opencast coal mine, where the field study was conducted, is one of the largest opencast coal mines of India. The mines exist in Singrauli coalfield of Northern Coalfields Limited (NCL). The rocks are of Gondwana formations having coal bearing barakars within it. A representative borehole section of the mine depicts the relative disposition of seams and partings (Fig. 1). The overburden bench (II bench) on which the studies were performed was 14-18 m high and was worked by 10 m^3 rope shovel in conjunction with 85 ton rear dump trucks. The bench was underlain by 40-50 m thick sandstone formation, below which there was a coal seam 18 m thick. The coal seams were worked by 4.6/10 m^3 rope shovel in conjunction with 50/85 ton rear dump trucks. The overburden bench consisted of fine grained sandstone with average uniaxial compressive strength of 12.5-20 MPa and average tensile strength of 1-2.0 MPa and average shear strength of 1-7 MPa. The values are based on the laboratory scale testing of representative rock samples as per the ISRM standards. No significant geological variations in form of major faults, folds or other geological discontinuities were witnessed on this bench.

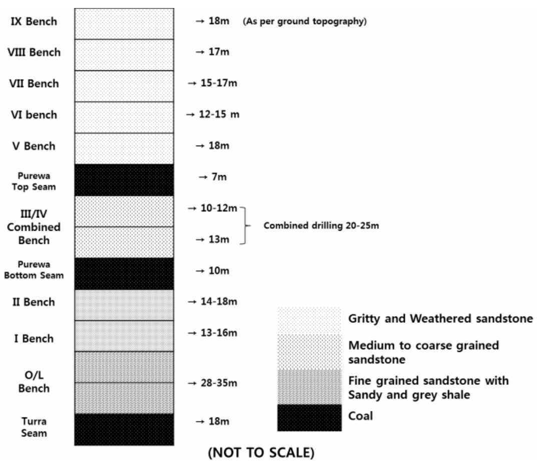

Fig. 1. A representative borehole section (not to scale) of the coal mine, showing the relative disposition of waste (overburden) rocks and three-coal seams in the study area

4. Field investigation and research methodology

To ensure the research objectives, full-scale blasts were conducted on the portion of overburden bench with average height of 14 m. Total five blasts were executed out of which two were fired on straight V type pattern (Fig. 2) and three on skewed V type firing pattern (Fig. 3). The important blast design parameters for all the blasts are tabulated in Table 1.

A perusal of the blast details in Table 1 reveal that all the blasts were bottom primed with shock tube

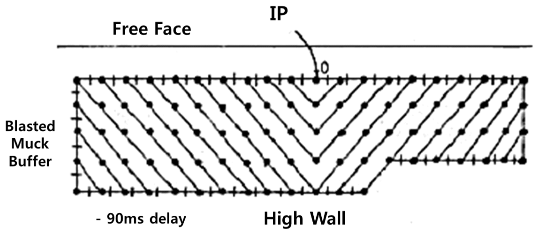

Fig. 2. A representative straight V-type firing pattern (not to scale) illustrating the initiation point (IP) and firing sequence with inter-row delay of 90 ms

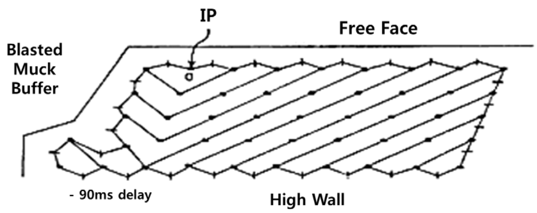

Fig. 3. A representative skewed V-type firing pattern (not to scale), with slanted limbs of the V, demonstrating the initiation point (IP) and firing sequence with inter-row delay of 90 ms is

system and were fired on similar delay pattern (Figs. 2~3) with almost similar blast design parameters but with two different firing patterns.

As all the blasts were conducted at different locations on the same overburden bench (which did not present any significant geologic anomalies) with identical explosive (site mixed emulsions), hence the rock and explosive parameters were assumed to be fairly uniform for the purpose of result interpretations. It may be of consequence to mention here that one-to-one congruity, of all the blast design parameters, especially for such large scale blasts, is absolutely difficult in field. Nevertheless, the blast design parameters can be considered to be almost identical so as to provide a ground for comparing and evaluating the fragmentation results (Table 1). As such, the influence of changing the firing pattern was investigated on fragmentation in the blasted muck piles.

To evaluate the fragmentation, image analysis techniques was deployed as it is a good and practical alternative to quantify the fragment size and its distribution in the blasted muck piles (Kandibotla et al., 1999). With the use of digital camera, a number of good quality and resolution photographs were captured on the blasted muck piles (with scaled targets kept carefully at the center of the image frame) during the entire excavation period of each blast. The field captured photographs were processed and analyzed by commercial state-of-art image analysis software; Fragalyst^{TM}. The output in terms of fragment sizes; mean (K50), coarse (K95) and maximum (K100) along with complete fragment size distribution plot is given by the software

Table 1. Skewed ‘V’ vs. straight V type pattern details

Parameter	Blast Number				
	1	2	3	4	5
Compressive strength (MPa)	12.5-20	12.5-20	12.5-20	12.5-20	12.5-20
Hole dia. (mm)	270	270	270	270	270
Avg. bench height. (m)	14	14	14	14	14
Avg. sub-grade (m)	2	2	2	2	2
SxB (m)	9x8	9x8	9x8	9x8	9x8
Avg. stemming length (m)	4.5	4.5	4.5	4.5	4.5
No. of holes	42	36	47	34	93
Total explosive quantity (Kg)	32626.25	26505	34748.50	26155.75	69577.25
Initiator	Shock tube	Shock tube	Shock tube	Shock tube	Shock tube
Drilling pattern	Skewed	Skewed	Skewed	Straight rectangular	Straight rectangular
Firing pattern	Skewed ‘V’	Skewed ‘V’	Skewed ‘V’	Straight ‘V’	Straight ‘V’
Avg. decking length (m)	1	1	1	1	1
Approx. broken volume of rock (m^3)	51744	45472	57792	42560	112000
Approx. area broken (m^2)	77x42	58x49	86x42	95x28	175x40
No. of rows	9	9	10	6	13
Inter-row delay (ms)	0/90	0/90	0/90	0/90	0/90/100
Column charge length (m)	10.5	10.5	10.5	10.5	10.5
Avg. P.F. (m^3/Kg)	1.59	1.71	1.66	1.63	1.61
M.F.S. (m)	0.2279	0.2511	0.2598	0.3331	0.3568
K95 (m)	0.355	0.393	0.410	0.533	0.524
K100 (m)	0.450	0.511	0.533	0.693	0.655
Total cycle time of the shovel (s)	28.5	28.0	29.5	35.0	41.0

after processing of the images. Rustan(1998) advocated the use of image analysis techniques with suitable software for quick, precise and almost inexpensive quantification of fragmentation.

Besides the image capturing, the field procedure also involved precise recording of total cycle time (up to two decimal places by precise stopwatch) for the 10 m^3 rope shovels excavating the muck piles in order to investigate the influence of fragmentation on the diggability of the shovels. The diggalibility may be defined as the ability of given excavator to excavate the muck with ease and rapidity. Pal Roy and Mondal (1999) mentioned that the diggability of excavator is related to the degree of fragmentation. Singh et al. (1999), also conducted a series of trial blasts is an Indian iron ore mine to report the influence of fragmentation on the performance of shovels. Marton and Crookes (2000) reported the reduction in productivity of the face excavators due to improper fragmentation. Singh and Yalcin (2002) also presented the importance of such studies in drawing inferences in respect of fragmentation.

5. Results and discussion

The results in terms of fragment sizes and excavator cycle time are given in Table 1. Complete fragment size distribution curves are also given in Figs. 4-8. In the skewed pattern of firing, as is clear from Fig. 3, the drill holes in the subsequent drilling rows were not drilled in a straight rectangular fashion but they were slightly skewed in the horizontal plane. Due to this skewness, the limbs of characteristic straight V got slanted (Fig. 3) resulting into increased effective spacing between the holes and reduced effective burden in the firing round. Given this, although the geometric spacing and burden for all the blasts was same area (9x8 m), the effective spacing and burden values got increased for the blasts fired on skewed pattern, such that the effective spacing to effective burden ratio for these blasts increased to 3 (the corresponding ratio for straight V type blasts was 2). This change was in line with earlier researches (Sarathy, 2000, Jimeno et al., 1995, Sarathy, 1991), which state that for the blasts

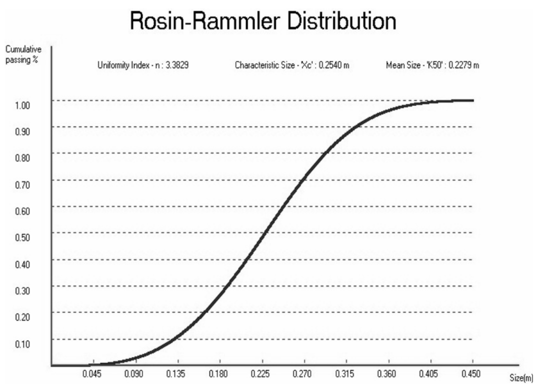

Fig. 4. Complete fragment size distribution (Rosin − Rammler distribution) for blast number 1 revealing the mean fragment size (K50), characteristic fragment size (Xc) and uniformity index

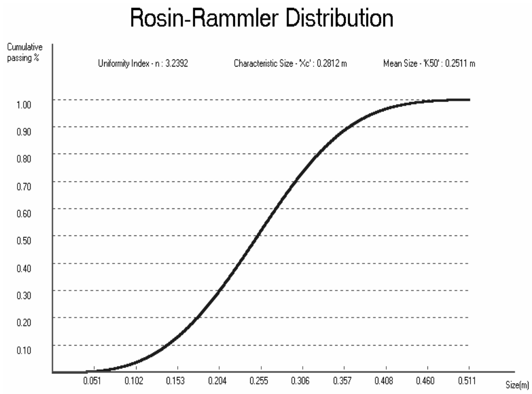

Fig. 5. Complete fragment size distribution (Rosin − Rammler distribution) for blast number 2 revealing the mean fragment size (K50), characteristic fragment size (Xc) and uniformity index

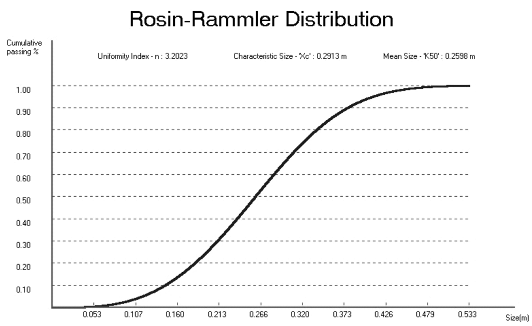

Fig. 6. Complete fragment size distribution (Rosin − Rammler distribution) for blast number 3 revealing the mean fragment size (K50), characteristic fragment size (Xc) and uniformity index

fired against one free face, the effective spacing to burden ratio of 3 or greater than 3 yields better results. Further, it may be appropriate to mention that on the basis of their tests Langerfors and Kihlstörm (1967) proposed S/B ratio of even up to 8 for better fragmentation in multi-row blasting. Singh and Sastry (1987) conducted a series of tests on Chunar sandstone models with instantaneous firing and found that S/B ratio of 3-4 yielded good fragmentation results. The fragment size results (Table 1) were improved. The increased spacing and reduced burden in the skewed V type pattern (during blast hole initiation) results in formation of slender burden rock mass, which was much easier to break. Further, the reduction in effective burden for the given bench height naturally implies an increase in the stiffness ratio of the bench during firing. This made the bench much more flexible and less resistant to breakage, as suggested in the flexural rupture theory (Ash & Smith, 1976). Additionally, the opportunity for in-flight collision also increases due to elongation of flanks of V. From the Rosin-Rammler fragment size distribution curves (Figs. 4-8), it is evident that the skewed blasts produced superior results in terms

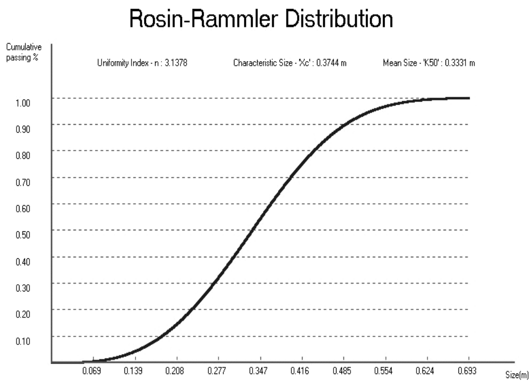

Fig. 7. Complete fragment size distribution (Rosin − Rammler distribution) for blast number 4 revealing the mean fragment size (K50), characteristic fragment size (Xc) and uniformity index

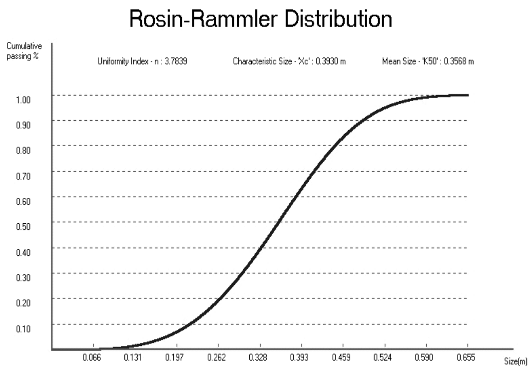

Fig. 8. Complete fragment size distribution (Rosin − Rammler distribution) for blast number 5 revealing the mean fragment size (K50), characteristic fragment size (Xc) and uniformity index

Fig. 9. Frequent occurrence of large-sized fragments within the muck piles, fired on straight V-type firing pattern, are clearly observed in this field photograph. The image frame shows a linear scale 0.5 m long wooden rod painted in dark brown color to contrast very well with the broken fragments.

Fig. 10. This figure demonstrates that the muck-piles fired on skewed V-type firing pattern, yielded finer fragmentation with better uniformity of fragment sizes within the muck pile in comparison to the blasts fired on straight-V type firing patterns. The linear scales, as appearing in the image frame, were 0.5 m long.

of fragment sizes and their distribution in the blasted muck pile.

Though large boulders were observed in the muck pile fired on straight V pattern (Fig. 9), the muck piles fired on skewed V type firing revealed fine fragmentation (Fig. 10). Fig. 11 shows the presence of very large fragments (boulders) along the perimeter/back rows of the blasts fired on straight V pattern. The occurrence of large sized boulders along the back rows can be attributed to restricted forward movement of the broken rocks in V firing patterns. This restricted forward displacement creates a buffer of broken rocks in front of subsequent firing rows, thus resulting in poorer fragmentation along the back rows. Literature suggests that the restricted forward movement in straight V patterns result into the upliftment of blasted muck, which is largely responsible for poor breakage and even cut offs (Kanchibotla, 2001). The greater the upliftment, the poorer would be the fragmentation at the collar region and along the back rows. On the other hand, good overall fragmentation was witnessed even along the back rows of the blasts fired on skewed V type firing (Fig. 12).

Fig. 11. This figure represents poor fragmentation with very large fragment sizes, along the back rows of the blasts fired on straight V-type firing pattern. Linear scale 0.5 m long appears in the picture.

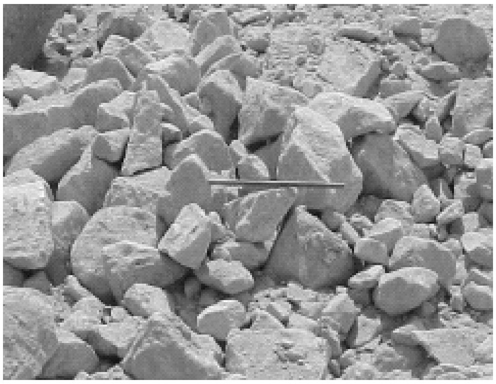

Fig. 12. This figure reveals good and uniform fragmentation along the back rows of the blasts fired on skewed V-type firing pattern. Fragmentation along the back rows is very consequential in governing the success of any blasting program. Linear scale 0.5 m long appears in the picture.

The fragment size results appear to be corroborated by the performance of the designated face shovels on the blasted muck piles. To explain this, for the blasts fired on skewed V type patterns, the total cycle time of shovel was significantly less (28-29.5 sec.) in comparison to the blasts fired on straight V pattern, where the total cycle time was 35-41 sec. Total cycle time of shovel can be split into five discrete time segments viz., digging, swing-to, unloading, swing-back time and bucket placement (at the blasted bench toe) time segment. The observed increase in the total cycle time of the shovel was due to the increase in digging and unloading time. Digging time was increased because of extra effort needed in digging and filling of buckets in the muck piles containing larger sized fragments. The unloading time of the muck in the trucks was augmented because of presence of large sized fragments within the fragmented rock in the muck piles. These large sized fragments got frequently jammed in the shovel bucket to delay the smooth unloading operation.

However, while implementing the skewed V type of pattern, some practical constraints were experienced. The drilling of such pattern needed a closer and strict supervision and, as such, drilling operation was time consuming. A slight variation is drilling plan was liable to badly affect the performance of blasts. As such, it calls for proper care in precisely marking the drill holes prior to drilling.

6. Conclusions

Following conclusions may be drawn from the present research work:

1) By changing the firing patterns, the effective spacing to effective burden ratio and the bench stiffness ratio at the time of firing can be considerably modified while adhering to same blast geometry parameters.
2) Augmentation of the effective spacing to effective burden ratio and the bench stiffness ratio at the time of firing, in the skewed V type pattern, enhances the degree of fragmentation in the blasted muck piles in comparison to the Straight V pattern.
3) The degree of fragmentation in the blasted muck piles affects the digging as well as unloading segment time of the operational cycle of the excavators.
4) Drilling of skewed pattern for skewed V firing is time consuming and calls for proper care, supervision and control to obviate even minor variations in the drilling plan.

Acknowledgement

The authors wish to extend their gratitude towards the excellent co-operation & support rendered by the staff and management of Northern Coalfields Ltd., Singrauli, District Sidhi (a subsidiary of Coal India Ltd.), India.

References

1. Ash, R.L. and N.S. Smith, 1976, Changing borehole length to improve breakage–A case history. 2nd Society of Explosive Engineers Conference on Explosive and Blasting Techniques, Kentucky, 1-12.
2. Jimeno, C.L., E.L. Jimeno and F.J.A. Carcedo, 1995, Drilling and Blasting of Rocks. A.A. Balkema, Rotterdam.
3. Kanchibotla, S.S., 2001, Optimum blasting? Is it minimum cost per broken rock or maximum value per broken rock?, Conference on Rock Breaking- Explo-2001, the Aus. IMM., Hunter Valley, 35-40.
4. Kanchibotla, S.S., W. Valery and S. Morrell, 1999, Modeling fines in blast fragmentation and its impact on crushing and grinding., Conference on Rock Breaking-Explo-99, the Aus. IMM., Kalgoorlie, 137-144.
5. Langerfors, U. and B. Kihlstörm, 1967, Modern Technique of Rock Blasting. John Wiley & Sons Inc., New York.
6. Marton, A. and R. Crookes, 1999, A case study in optimizing fragmentation., Conference on Rock Breaking-Explo-99, the Aus. IMM., Kalgoorlie, 35-43.
7. Pal Roy, P. and S.K. Mondal, 1999, Techno-economic assessment of drilling and blasting parameters – some in-depth studies. Journal of Mines Metals and Fuels, 47, 381-389.
8. Rustan, P.A., 1998, Automatic image processing and analysis of rock fragmentation – Comparison of systems and new guidelines for testing the systems. Fragblast: the International Journal for Blasting and Fragmentation, 2, 15-23.
9. Sarathy, M.O., 1991, Delay blasting – An inexpensive tool for reduced total mining costs., The Indian Mining and Engineering Journal., 30, 51-58.
10. Sarathy, M.O., 2000, Optimum blasting in surface mines – major issues. Seminar on Blasting Objectives and Risk Management, Hyderabad, 1-29.
11. Singh, D.P. and V.R.S. Sastry, 1987, An investigation into the effect of blast geometry on rock fragmentation. J. Mines, Metals and Fuels, 39, 226-233.
12. Singh, S.C., B.D. Baijal and M. Fasihuddin, 1999, Introduction of advanced blasting technology at Noamundi iron mines, Tata Search Magazine (in-house magazine), 171-175.
13. Singh, S.P. and T. Yalcin, 2002, Effect of muck size distribution on scooping operations. J. Int. Soc. of Explosive Engineers, 1, 315-325.

Piyush Rai

1987 인도 Jodhpur 대학 광산공학과 학사
1992 인도 Banaras 대학 광산공학과 석사
2002 인도 Banaras 대학 광산공학과 박사

Tel: +91-542-670-2509
E-mail: piyushrai.bhu.@gmail.com
현재 Banaras 대학 광산공학과 Associate Professor
현재 전남대학교 에너지자원공학과 초빙교수

양 형 식

1979 서울대학교 자원공학과 학사
1981 서울대학교 자원공학과 석사
1987 서울대학교 자원공학과 박사

Tel: 062-530-1724
E-mail: hsyang@jnu.ac.kr
현재 전남대학교 에너지자원공학과 교수