

Chip size characterization for selecting optimum production parameters of surface miner operating in a coal mine

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Coal production using surface miner technology is a well-accepted method today in Indian coal mines contributing a sizeable proportion to the overall production. Production of coal chips of desired size is an important parameter in surface miner performance evaluation in terms of tonnes per hour as well as fulfilment of the need of the consumers. The demand for an average chip size in the range 100–150 mm thermal power plants is growing and this size also fetches a premium price compared to blasted lumpy coal. A field study was conducted at Sonepur Bazari opencast mine, Eastern coalfields (ECL), West Bengal, India for evaluating the cutting operation and performance of a 2200 SM surface miner under varied operational and rock mass conditions. An imaging technique coupled with Fragalyst software was used for grabbing and analysing the sizes of chips produced by surface miner. The wide variation in chip size formation observed in the field was due to the fluctuations in cutting speed and also the presence of joints. This communication reports the study carried out on surface miner to develop a new methodology for characterizing chip size, fixing the optimum machine operating parameters for a desired chip size and also the production potential.

Keywords: Surface miner technology, chip size, coal production, rock mass.

CURRENTLY, 89% of coal production comes from opencast mines in India, a scenario which may continue for another two decades¹. Production by surface miners alone in Coal India Limited (CIL) during 2010–2011 was about 103 million tonnes, which is 26% of the total production, indicating the supremacy of this new technology over other conventional ones such as drilling and blasting, shovel-dumper and bucket-wheel excavator². Surface miner, also called continuous surface miner, is a technology to cut and load material at one go. It is one of the best alternatives to drilling and blasting technique for medium strength to soft rocks. This technology overcomes various pragmatic problems encountered in blasting like flyrock, noise, ground vibrations, etc. and is considered to be an eco-friendly technology. It eliminates primary and even secondary crushing because of reduced

chip size in cutting, which is often the requirement of many power plants. The first Wirtgen surface miner was introduced in Lakhanpur opencast project of Mahanadi Coalfields Limited (MCL), a subsidiary of CIL, way back in 1999. Presently, 27 surface miners of Wirtgen, L&T and Bitelli-make are operating in MCL alone. Around 40 surface miners are now operating in different subsidiaries of CIL and Singareni Collieries Company Ltd. Out of 300 surface miners in productive use around the world, some 105 operating machines are in India³. Surface miner is a proven versatile machine with cutting capability in soft and medium hard rock with compressive strength in the range of 100–120 MPa (ref. 4). According to Bordia⁵, these machines proved to be successful for multi-seam coal deposits, including stone partings with compressive strengths up to 100 MPa. The maximum depth of cutting in such cases was 0.6 m. The weak structure of rock adds up to its capability of cutting even to higher values in the range 120–150 MPa.

A study was conducted in Sonepur Bazari opencast (SBOC) mine of Eastern Coalfields Limited (ECL), West Bengal, India to develop a method for evaluating the cuttability of rocks through chip size produced. A portion of the large opencast mine is being worked out by 2200 SM model surface miner of Wirtgen-make. It is of prime importance to evaluate the production quantity and its quality for cutting performance evaluation and optimization. It is known that the chip size of the cut material depends on cutting speed of the surface miner and rotational speed of the cutting drum. Theoretically, it is equivalent to tool advance per revolution. The presence of joints/cleats and distance between the joints/cleats affect the final size of the chip.

The size of the chip produced during cutting is important both from the producer and consumer viewpoint. Thermal power plants need sized coal with a size range between 100 and 150 mm. Such consumers even pay higher premium to producers for this range of coal chip size. An extra price of Rs 15–20/tonne is paid for sized and lumpy power grade coal which may vary based on the grade of coal. Generation of small size chips leads to more fines generation and consequently affects both quantity and quality of production. Therefore, it is important for producers to operate the surface miner in such a way that the chip of desired size can be achieved giving due importance to intact rock, rock mass and machine parameters. This is to optimize the energy, diesel and pick consumption during operation, which is vital for the profitable operation of surface miners.

SBOC mine, ECL is located in the eastern part of Raniganj Coalfield, West Bengal, India. This coalfield is in a synclinal basin with the Gondwana sediments lying unconformably over the basement and the southern boundary is marked by major faults. A larger part of the coalfield is occupied by Barakar and Raniganj coal measures. Presently, there are four workable coal seams in

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Sonepur Bazari, namely R-VII, R-VI, R-V and R-IV. The surface miner is deployed in R-VI seam at the location depicted in Figure 1. The technical specifications of 2200 SM surface miner are given in Table 1.

The cutting operation of the surface miner in the mine is on empty travel-back mode. In this method the surface miner cuts the material from one end of the pit and the cutting drum is raised and moved back to the starting end without turning after completion of the full cut. The material is not cut during the backward movement, i.e. it travels back empty. After relocating the initial point, the machine is set for a new cut in the adjacent strip. This method is generally adopted for a mine having field length less than 200 m, since the turning time becomes more than the empty travel time⁶. It is also applicable in constrained pit-end condition and the machine is not able to turn as the pit width is not sufficient to allow the turning of the machine at the end of a cut.

The productivity of a surface miner depends on the length of the available working area. Longer strike lengths will enhance the productivity, because only a smaller amount of time is spent in manoeuvring from one cut to the next. In such cases turn back method is preferred. The strike length of the face in this study is around 150 m. Often this is the case in coal mines due to shorter overburden stretch planned for excavation with minimum

lag between coal and overburden excavation for optimizing net present value of the mine.

Windrowing system is adopted in this mine. In this system, the machine is not fitted with the discharge belt. The scraper plate behind the drum is modified and a door is provided which allows the cut material to heap behind the machine in a row as shown in Figure 2.

Cut material can be loaded later onto a dumper with front-end loader and scrapper. Thus, the windrowing system is independent of loading and transportation of material. The overall efficiency (including fuel efficiency) is more in windrowing as the machine is devoid of the discharge belt, and thus is lighter, more balanced and requires less energy for operation. Therefore, it is the most productive mode of use of a surface miner and hence is adopted often unless water conditions demand immediate removal of cut material by belts (like limestone) for maintaining quality.

The cutting speed of the surface miner during the study ranged between 12 and 22 m/min with an average depth of cut of 18 cm producing coal in the range 454–566 tonnes/h. In portions identified with hard bands, the cutting speed was reduced to 12–14 m/min for preventing from overloading. The average diesel and pick consumption were found to be 64 l/h and 4–5 respectively, for an operational time of 14–15 h/day. The pick consumption per thousand tonnes varied between 0.71 and 0.82.

Images of the cut heaps were taken for analysis of chip size during the operation of the surface miner (model no. 2200 SM) at SBOC mine. Photographs of the cut materials were taken at different locations to get an overall picture of chip formation. The study was conducted at three locations. Before taking photographs a measuring scale was kept on heaps horizontally for size calibration of the image. The photographs were taken along the slope of the heap. The chip size analysis was conducted using Fragalyst software (Version 4.0) to obtain mean chip size (K_{50}) through Rosin–Rammler curve.

The Fragalyst software has been developed jointly by Central Institute of Mining & Fuel Research (CIMFR)

Table 1. Technical specifications of 2200 SM model surface miner used in Sonepur Bazari opencast (SBOC) mine, Eastern Coalfields Limited (ECL), India

Parameters	2200 SM
Cutting width (m)	2.20
Cutting depth (m)	0.35
Drum diameter (m)	1.14
Travel speed (km/min)	0–5
Engine (HP)	800
Weight (t)	51.0
No. of tools	76
Pick spacing (mm)	38

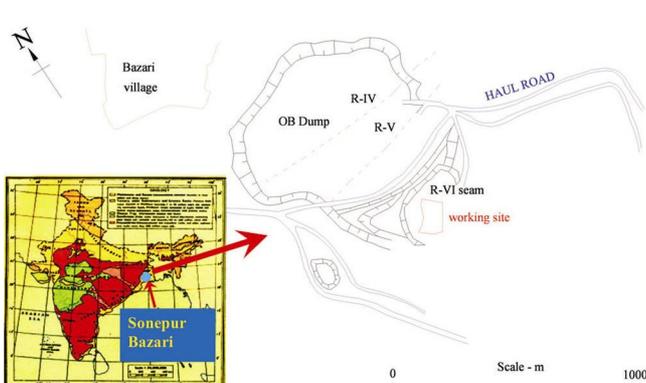


Figure 1. Working site of surface miner in Sonepur Bazari opencast (SBOC) mine, Eastern Coalfields Limited (ECL), India.



Figure 2. Windrowing discharge system of surface miner at SBOC mine, ECL.

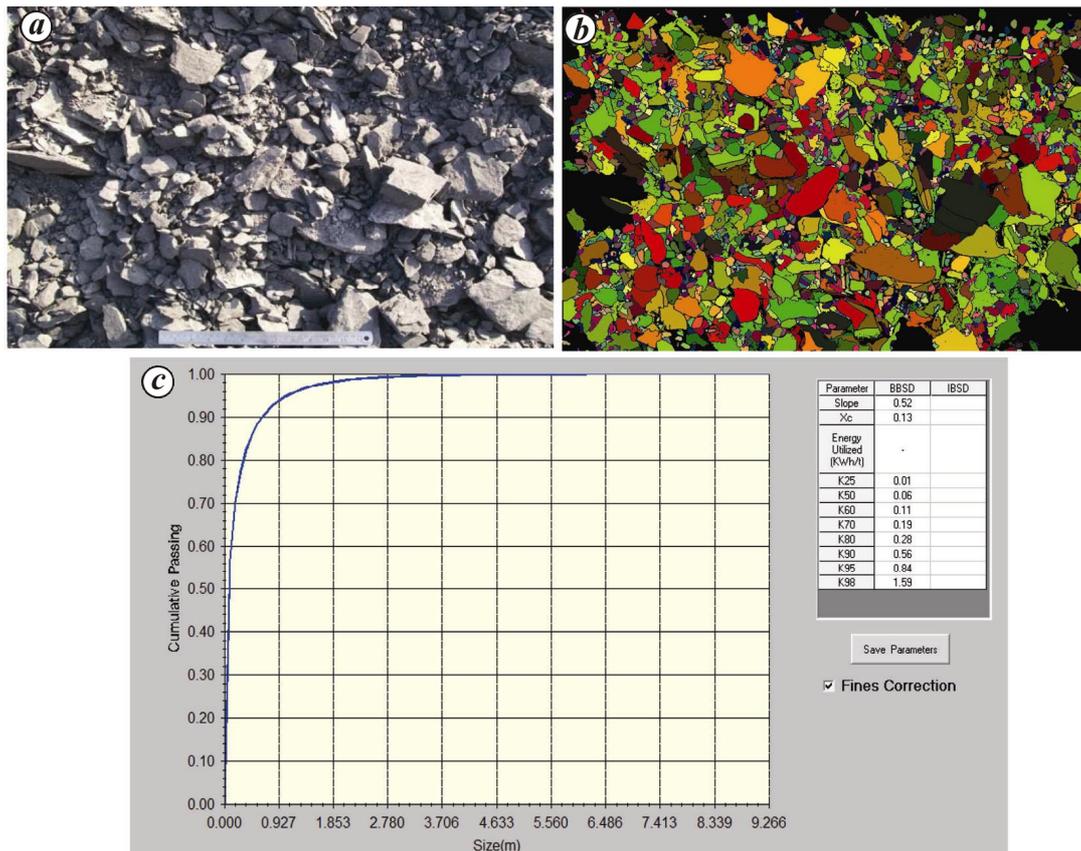


Figure 3. a, Photograph of cut material at location 1. b, Segment of cut materials of location 1 after edge edition. c, Cut size distribution with correction for fines of location 1.

and Wavelet Group for fragmentation/chip size analysis. It is designed as a Windows-based fragment image analysis software package which was developed to assist mining engineers. The system accepts a digitized image of a pile of cut materials and performs a computerized analysis of the image for obtaining vital size and shape-related information of the visible sizes. Cut size analysis involves calculating the diameter, volume, weight, sphericity and shape factor of the various cut fragments present in the image of a particular muck left behind by the surface miner. To generate the above parameters, the system performs various image-processing operations on the given image. Along with the standard image-processing functions, the package is provided with an intelligent editor to edit and fine-tune the boundaries detected for the various cut sizes. The system will produce graphical results in the form of various distributions like the Rosin–Rammler curve and the normal distributions.

In the chip size analysis using Fragalyst-4.0 software, the original image sizes are reduced to about 1500 × 800 pixels, as the original images have large pixels which cannot be processed by the software. The images are calibrated with the help of ‘aspect ratio’ option in the software, which takes care of the tilt of the rock faces with respect to the camera. The chip images obtained by the

software are manually edited in order to avoid any missing fragment detected by the software. After properly editing the fragments, the analysis is carried out by taking the average bulk density of coal as 1.3 t/m³. The cut size distributions using Rosin–Rammler equation after the fines correction along with the segments of the chip obtained from the Fragalyst-4.0 software of one of the locations are given in Figure 3 a–c.

The number of coal chips obtained after careful edition of the size was 419, 451 and 712 respectively. The average cut size (K_{50}) obtained after correction for the fines in locations 1, 2 and 3 is 0.06, 0.20 and 0.13 m respectively. The overall chip size of coal obtained by the analysis was 130 mm. It is evident from Figure 3 a that the mean chip size obtained after the fines correction corroborates the field observation. The causes of chip size variation have been analysed and are discussed below.

Rock mass characterization: Scan line survey was carried out at the cutting face created by surface miner to determine the nature and distribution of discontinuities. At places, coal layers were intersected by numerous joints/cleats at an interval of 15–20 cm in all the three directions⁷. The coal formation was relatively uniform and, at places, it was virtually free from any alternate layer.

Table 2. Mean chip size obtained at different locations at SBOC mine, ECL

Location no.	K_{50} (m)		
	After fines correction	<i>In situ</i> P-wave velocity (m/s)	Joint spacing (Js) (cm)
1	0.06	654	$J_s > 0.50$
2	0.20	425	$J_s < 20$
3	0.13	520	$20 < J_s < 50$
Average	0.13	533	

The *in situ* P-wave velocity (IV_p) was measured by Mc Seis 3 Model 1817 (three-channel seismograph, Handy Viewer of OYO Corporation, Japan), as this parameter represents the structure and degree of rock mass fracturing, together. Three geophones were fixed in the ground by quick setting cement (POP) at an interval of 1.5–2.0 m in a line. Vibration was created in the ground by hammering on the hard surface around 1.5–2.0 m away from the first geophone.

The low values of IV_p , ranging from 425 to 654 m/s, corroborate the presence of joints/cleats at close interval, in addition to material softness. The chip size variation and corresponding *in situ* P-wave velocity are given in Table 2. The joints/cleats sometimes get dislodged from their *in situ* position by the movement of the crawler of surface miner leading to larger size chip formation. Thus, the variation in chip size was also due to the rock structure and strength.

Cutting speed – The size of the chip varies with cutting speed of the surface miner and is generally equivalent to tool advance per revolution. Theoretically, cutting speed should have been around 10 m/min at 80 rpm drum rotational speed to achieve 130 mm chip size for 2200 SM model according to the studies carried out by Prakash *et al.*⁸ (Figure 4). Instead, the size of coal chips varied from fines to more than 200 mm as observed during the study through image analysis at different locations. This variation can be attributed to change in the rock mass properties.

It was observed that in feebly to moderately jointed rock (location 3), the actual cutting speed of the surface miner was 12–14 m/min. But in highly jointed area (location 1), the cutting speed was found to range between 18 and 22 m/min.

For a desired chip size, the actual cutting speed of the surface miner under varied rock mass conditions can be estimated from the following relations:

$$CS_a = \frac{CS_{th}}{IV_p} \quad (\text{for jointed rock mass}), \quad (1)$$

$$CS_a = CS_{th} \quad (\text{for massive rock mass}), \quad (2)$$

where CS_a is the actual cutting speed (m/min), CS_{th} the theoretical cutting speed of surface miner for desired

chip size (m/min), and IV_p the *in situ* P-wave velocity (km/s).

Equation (1) holds good for *in situ* P-wave velocity (IV_p) < 1 km/s. The actual production now can be estimated as

$$P_a = 60 \cdot CS_a \cdot DW \cdot DOC, \quad (3)$$

where P_a is the actual the production (m^3/h).

Considering the average *in situ* P-wave velocity as 533 m/s, the actual cutting speed in highly jointed rock mass condition comes to 19 m/min for achieving an average chip size of 130 mm. Production calculated from eq. (2) in different rock mass conditions, by taking coal density as $1.3 t/m^3$, is given in Table 3.

The production will vary between 309 and 587 t/h depending upon the rock mass condition. The above relations need to be further refined by carrying out similar exercises in varied geo-mining conditions.

Performance analysis of surface miner through the chip size determination for a 2200 SM model was carried out at SBOC mine. The machine operated in empty travel back mode over a face length of 150 m. Windrowing system was adopted for realizing higher production. The cutting speed of the surface miner ranged between 12 and 22 m/min with 18 cm depth of cut producing at a rate of 454–566 t/h. The average chip size analysed by Fragalyst software after the fines correction was found to be 130 mm. The variation in the chip size formation was mainly due to cutting speed variation of the surface miner and also due to the presence of joints/cleats. Dislodgement of *in situ* coal from joints due to the movement and heavy weight of the machine led to the formation of larger size of coal chips in certain cases. The influence of rock mass properties, as experienced in SBOC mine, needs to be incorporated for estimating the actual cutting speed of the surface miner for the desired chip size. It was found that the actual cutting speed can be estimated more rationally using *in situ* P-wave velocity of rock mass as it represents both the strength and structure of the rock mass. Enhanced production can be achieved in highly jointed rocks up to 587 t/h, with an average chip size of 130 mm. But in massive rock mass conditions, production may be reduced to 309 t/h for acquiring an average 130 mm chip size of coal.

There is optimum chip size requirement which needs to be met during cutting with surface miners for better profitability. Deviation from optimum size can lead to sizeable loss in revenue apart from generating various environmental concerns such as dust and fines. Optimum chip size is primarily achieved through selection of suitable cutting and drum speed in a given rock/rock mass condition. A method has been developed to achieve the desired chip size in this study through varying machine and rock mass parameters. Alternatively, for a given rock mass condition optimum machine operating parameters

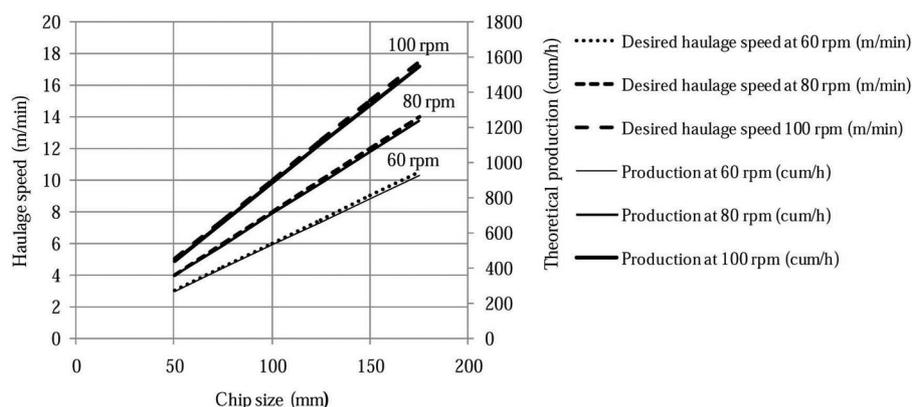


Figure 4. Cutting and drum speed for desired theoretical production and chip size.

Table 3. Production estimation under varied rock mass conditions

Highly jointed rock		Low to moderately jointed rock		Massive rock	
Average joint spacing (Js; cm)					
<20		20–50		>50	
Actual cutting speed (m/min)	Actual production (t/h)	Actual cutting speed (m/min)	Actual production (t/h)	Actual cutting speed (m/min)	Actual production (t/h)
19	587	13	402	10	309

can be adopted. The average size of the cut material was determined by Fragalyst software, as it is practically not viable to assess the average chip size by eye observation in the field. The chip size varied in the range 6–200 mm. The cutting speed of 2200 SM surface miner ranging from 12–22 m/min with joints/cleats at 15–20 cm in all directions resulted in an average chip size formation of 130 mm. It was inferred from the study that machine operating conditions, i.e. cutting speed and drum speed of the surface miner as well as the influence of rock mass properties, especially in the form of joints/cleats at close interval, led to variation in chip size formation. Dislodgement of *in situ* coal from the joints due to the movement of the surface miner led to larger chip generation. Production estimated from the new methodology varies from 309 and 587 t/h depending upon rock mass conditions, i.e. for massive to highly jointed rock for achieving an average chip size of 130 mm. The actual production in the mine varied between 454 and 566 t/h. More investigations are needed under varied rock conditions for further refining the relations developed in this study.

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