CHANDAN KUMAR
V.M.S.R. MURTHY
L.A.KUMARASWAMIDHAS
and
AMAR PRAKASH

Influence of cutting drum specifications on the production performance of surface miner under varied rock strength – some investigations

Application of surface miners has increased phenomenally all around the world for rock excavation in varied rock mass conditions. There are numerous models of surface miners with wide range of specifications. Machine specifications, specially, power and drum dimensions (drum width and diameter) as well as operating parameter, i.e., depth of cut are related to production. This is in addition to the allowable cutting speed (m/s). Ability of surface miner to operate and cut effectively in rock is limited to strength property of rock. Uniaxial compressive strength of rock is one of the important controlling parameters for excavation by surface miner. An in-depth knowledge of rock and machine interaction is imperative for smooth operation and mass production of surface miner. The paper presents the influence of uniaxial compressive strength of rock on normalized production for varied rock types. Production has been projected for different machine specifications especially, drum width, drum diameter and depth of cut (i.e., contact area of drum) and machine power for rocks having different uniaxial compressive strength. Production has also been analyzed with varying depth of cut for different rock strength. Combining various machine and rock parameters an empirical relation has been established to predict the production for a given surface miner of known power rating. Alternately, the power required for achieving a given production can also be arrived from the developed equation. However, the actual production could vary depending on the structure of rocks, abrasivity of material and also the cutting drum design variations (vane spacing, pick spacing, angle of wrap, etc.) which need further studies.

Keywords: *Surface miner; uniaxial compressive strength; normalized production; depth of cut*

Messrs. Chandan Kumar, L.A.Kumaraswamidhas, Department of Mining Machinery Engineering, V.M.S.R. Murthy, Department of Mining Engineering, Indian School of Mines, Dhanbad, India and Amar Prakash, Central Institute of Mining & Fuel Research, Dhanbad, India. raa.swa@gmail.com

I. Introduction

In India, since nationalization, opencast mining has become more popular than underground mining owing to the rising demand of minerals and the need to have productive, economic and safe mining methods. There is also a growing preference to deploy mechanical rock excavation systems in opencast mines for enhancing production. Application of surface miner at different coal, limestone, gypsum, lignite, salt, phosphate, bauxite, and iron ore projects around the globe and India, is catching up since early 1990s. Surface miners are machines made for an efficient and continuous mining operation. Presently, surface miners are contributing in a number of projects in various parts of the globe, especially in USA, Russia, Australia and Bosnia apart from India. Out of a global population of 422 surface miners about 114 surface miners are operating in India [1]. The elimination of drilling, blasting, loading and crushing operations with one single machine is also one of the striking reasons for its increased application. Surface miners are increasingly being used owing to their ability to win thin bands selectively, which is a primary requirement in most of the limestone, coal and iron ore mines to maintain desired quality and chip size. Thermal power plants and cement industries require mineral of a desired chip size for their consumption which can be obtained by surface miner. This necessitates an in-depth study of different machine configurations, their production and rock mass conditions. Surface miners are having different configurations such as drum positions, cutting width, capacity, and weight with different manufactures producing them globally as shown in Table I.

Surface miners with middle drum configuration are mostly used for mining of minerals/rocks in different mines and are the subject of investigation.

II. Methodology

A. Surface Miner

Surface miner is a continuous mining machine and is being manufactured in India and abroad owing to enhanced

Table I. Types of surface miners based on machine specifications

Parameters	Types of surface miner		
Drum position	Middle drum	Rear cutting drum	Front cutting wheel
Cutting width (mm)	250-4200	5250	7100
Capacity (tph)	For all machines output is related to material characteristics		
Weight (tonne)	40-190	135	540
Manufactures	Wirtgen, Bitelli, L&T, Puzzolana and Huron	Vermeer, Tesmec, Voest Alpine	Krupp Fordertechnik & Tenova Takraf

demand of production in various mining industries like coal, limestone, gypsum, bauxite etc. Surface miners have proved to be one of the major mechanical excavators, particularly, in soft and medium hard rock for meeting the higher demand for minerals. Selecting proper specifications of surface miner in a given geo-excavation set up is still a challenge faced by excavation engineers. Selection and performance of surface miner is influenced by a host of intact rock/rock mass properties apart from various machine design and operating parameters. Surface miner is predominantly used for excavating soft and medium hard rock with the compressive strength in the range of 20-120 MPa [2].

B. Types of Surface Miner

Different types of surface miners are manufactured today based on cutting drum placement and design specifications [3], [4].

(a) Milling type: This type of surface miner includes Wirtgen or Bitelli machines, Easi-Miner from Huron, Man Takraf surface miner, L&T surface miner and Vermeer Terrain Leveller. In most of these machines, the cutting drum is positioned below the machine in between the front and rear crawlers. The Vermeer cutting drum is at the end of the machine; it is also wider than the machine and uses top-down cutting which allows the cutter teeth to gain penetration without using machine's tractive effort. In Man Takraf surface miner (MTS250 and 1250) the cutting drum is fixed in front of the machine. The milling type miner can cut rocks with compressive strength in the range of 80–100 MPa and has been claimed to be able to negotiate rocks of 140–150 MPa compressive strength, with reduced production though.

(b) Bucket wheel type: This type of surface miner, based originally on Satterwhite machine, is marketed by Thyssenkrupp Fordertechnik. In this machine (KSM2000), 4 parallel bucket wheels are mounted on a main frame without boom. The machine has a theoretical output of approximately 1000–1400 bm3/h in material of average uniaxial compressive strength of 20–30 MPa.

(c) Ranging-shearer-drum type: This type of surface miner is based on underground drum type continuous miner, represented by Voest Alpine's VASM-2 and Rahco's CME-12. The ranging-shearer-drum type miners can cut rocks up to 120 MPa, though their economic range of operation is 80 MPa.

C. Working Principle of Surface Miner

The surface miner is a crawler-mounted machine having a cutting milling drum located between two sets of crawlers and is positioned at the center of the machine. It has a powerful diesel engine and hydraulic pumps for delivering the power to the cutting drum. The cutting drum is made up of special alloy steel with replaceable tungsten carbide cutting tools which can be quickly detached or fixed. The drum can be lowered or lifted by hydraulic system with powerful hydraulic motors thereby varying the depth of cut. The material cut is loaded onto primary and secondary discharge conveyors for loading the same onto the loading equipment. The rear crawler travel at a lower level than the front crawlers to adjust to the required depth of cut. Dust is suppressed at the source itself by water spraying on to the milling drum thereby making it an environment friendly machine. As the cut material are of uniform size and the impact on the crusher while crushing is reduced. An electronically controlled depth regulator controls the thickness of the layer to be cut. Whenever, there is an intermittent reject band encountered, the same is eliminated by loading and dumping it separately in the specified dump thereby facilitating selective mining with this machine.

D. Machine Specifications

There are many models of surface miner available in market designed with different drum width and depth of cut. The specifications relating to design and operating parameters of some of the middle drum type surface miners are detailed in Table II [5], [6], [7]. Maximum cutting speed and depth of cut mentioned in the table are as specified by manufacturer.

In the present study, the power rating of surface miner ranged from 450 to 1194 kW. Drum width and diameter varied from 2.0 to 4.2 m and 1.04 to 1.86 m respectively. Maximum possible depth of cut varied with drum diameter and ranged

Table II. Specifications of various models of surface miner

	Model	Power (kW)	Design parameters		Operating parameters	
			W (m)	D (m)	CS (m/min)	DOC (m)
1	SF202M	515	2.0	1.04	0-25	0.25
2	2100SM	450	2.1	1.04	0-25	0.30
3	2200SM	597	2.2	1.14	0-25	0.35
4	KSM 223	597	2.2	1.14	0-25	0.35
5	2500SM	783	2.5	1.40	0-25	0.60
6	KSM 304	895	3.0	1.35	0-20	0.40
7	3800SM	950	3.8	1.40	0-20	0.60
8	4200SM	1194	4.2	1.86	0-20	0.80

Note: W = width of drum (m), D = diameter of drum (m), CS = cutting speed (m/min), DOC = depth of cut (m) from 0.25 to 0.80 m. It may be observed that the cutting speed decreases with increase in depth of cut.

E. Influence of rock properties on performance of surface miner

Uniaxial compressive strength of the rock and machine power are the most important factors influencing the production rate of surface miner [8]. Depth of cutting, uniaxial compressive strength and engine power have a significant impact on the cutting speed. A relationship was proposed between the production rate of continuous surface miners and the uniaxial compressive strength of rock based on various experimental data [9]. The performance of various models of surface miners were reviewed globally on varied rock types namely, coal, limestone, gypsum, bauxite, dolomite, shale, sandstone, granite, clay schist and hematite. Surface miners deployed in rocks were having compressive strength ranging from 10 to 200 MPa. Surface miners of Wirtgen, L&T and Bitelli make were studied in detail. Thus, it is evident that performance of surface miner depends on rock properties and machine parameters.

F. Normalization of Production

The different models of surface miner of varied drum dimensions were used. Production is directly influenced by cutting drum dimensions i.e. drum width and drum diameter. Hence actual production was normalized with respect to contact area of drum to eliminate the influence of drum dimensions. The drum cuts the rock in arc as shown in Fig.1. The arc length in contact with rock is expressed as in equation 1[10].

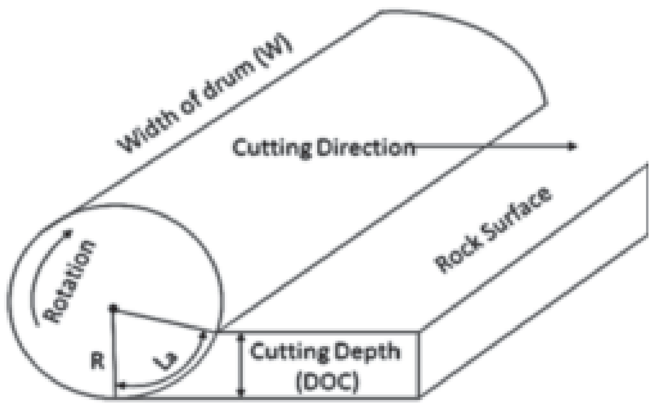

Fig.1 Length of arc of drum in contact with the rock cutting operation

Where,

La = contact length/length of arc of drum in contact with rock (m)

R = radius of cutting drum (m)

W = width of cutting drum (m)

DOC = depth of cut (m)

The length of arc depends on depth of cut. The equation 1 is based on various drum design specifications available. This relation holds good provided that depth of cut is less than radius of drum. Thus, the contact area is expressed as,

$$L_a = \frac{2\pi R \cos^{-1}\left(\frac{R-DOC}{R}\right)}{360} \quad \text{... ... 1}$$

$$CA = L_a \times W \quad \text{... ... 2}$$

Where,

CA = contact area of cutting drum (m^2)

La = contact length of cutting drum (m)

W = width of cutting drum (m)

The contact length (La) and contact area (CA) of various models of surface miners (SF 202M, 2100 SM, 2200 SM, KSM 223, 2500 SM, KSM 304, 3800 SM and 4200 SM) were calculated from the above equation 1 and are shown in Table III.

Table III. Contact length and contact area of various models

	Model	W (m)	DOC (m)	R (m)	L_a(m)	CA (m^2)
1	SF 202M	2.0	0.25	0.52	0.53	1.06
2	2100 SM	2.1	0.30	0.52	0.59	1.24
3	2200 SM	2.2	0.35	0.57	0.67	1.47
4	KSM 223	2.2	0.35	0.57	0.67	1.47
5	2500 SM	2.5	0.60	0.70	0.99	2.49
6	KSM 304	3.0	0.40	0.68	0.77	2.33
7	3800 SM	3.8	0.60	0.70	0.99	3.79
8	4200 SM	4.2	0.80	0.93	1.33	5.58

The surface miner machine specifications are having direct influence on contact area which ranges from 1.06 to 5.58 m^2 for the miners studied. The contact area represents all the parameters (drum radius, depth of cut and drum width) in its entirety and influences the production. Thus it is a better descriptor to estimate the possible production.

Normalized production as described in the above section is correlated with uniaxial compressive strength as shown in Fig.2 for various rock types.

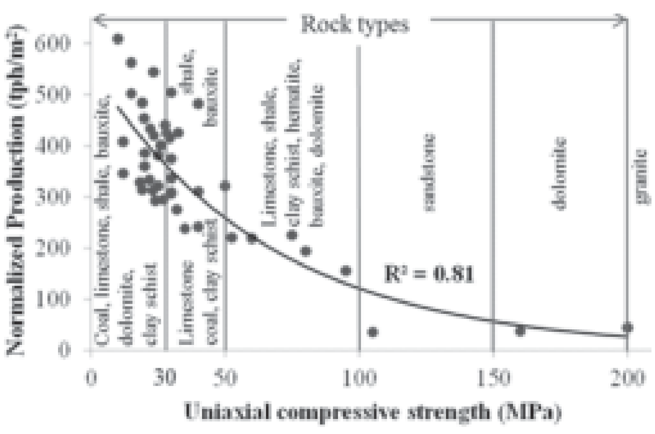

Fig.2 Normalized production with uniaxial compressive strength for various rock types

Normalized production is inversely proportional to uniaxial compressive strength of rock and is expressed as:

$$P_n = 553.67e^{-0.015\sigma_c} \quad \text{... ... 3}$$

Where,

P_n = normalized production (tph/ m^2)

σ_c = uniaxial compressive strength (MPa)

The index of determination (R^2) of the above relation was found to be 0.81. Limited number of surface miners are found to be used in compressive strength ranging above 50 MPa whereas large number of surface miners are deployed in rock strength ranging around 30 MPa. A few surface miners were used in rock types like dolomite and granite having compressive strength above 100 MPa showed normalized production below 50 tonnes per hour (tph). The normalized production was found to be less than 250 tph for compressive strength ranging between 50 to 100 MPa.

III. Results and discussion

A. Influence of rock strength

The normalized production of surface miner is inversely proportional to strength of rock as depicted in Fig.2. The production performance is also related to width of drum, depth of cut and machine power. Production has been projected based on uniaxial compressive strength of rock from the equation 1 for varied machine specifications such as, drum width (4.2 m, 3.8 m, 3.0 m, 2.5 m, 2.2 m, 2.1 m, 2.0 m) and depth of cut (0.8 m, 0.6 m, 0.4 m, 0.3 and 0.25 m). Production is also projected with different machine power, ranging from 515 kW to 1194 kW as shown in Fig.3.

Where,

P_o = machine power

W = width of drum

DOC = depth of cut

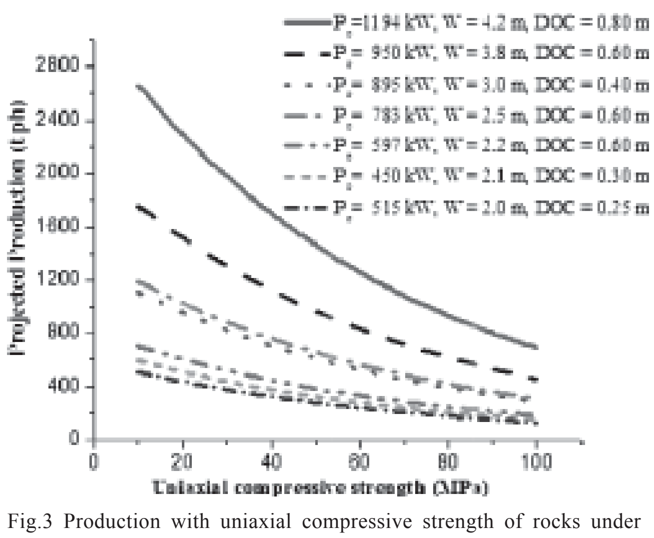

Fig.3 Production with uniaxial compressive strength of rocks under varied machine parameters

The projected production was calculated for compressive strength up to 100 MPa because limited surface miners were found to be deployed beyond this range. Larger drum dimensions, greater depth of cut with high machine power showed higher range of productions in comparison with others.

B. Influence of depth of cut

Actual depth of cut in real ground condition is much less than specifications provided by manufactures. Uniaxial compressive strength is one of the limiting factors to influence the depth of cut of surface miner in operation. An experimental study carried out to evaluate some coal cutting theories for continuous miners proved that the normal cutting forces acting on a cutter increased linearly with depth of cut [11]. Therefore, production has been projected for varied depth of cut from 0.1 to 0.8 m and taking uniaxial compressive strength into consideration as shown in Figs. 4, 5, 6 and 7.

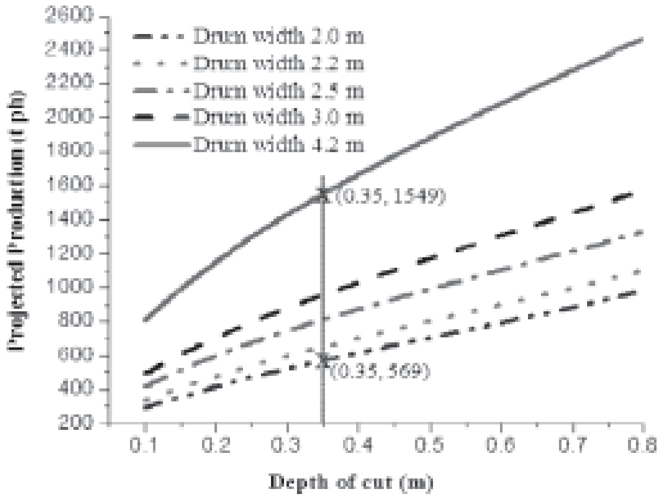

Fig.4 Production with depth of cut on varied drum width at UCS 15 MPa

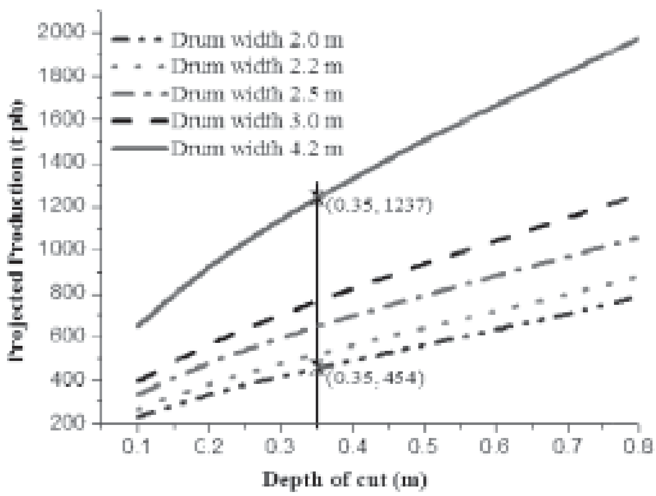

Fig.5 Production with depth of cut on varied drum width at UCS 30 MPa

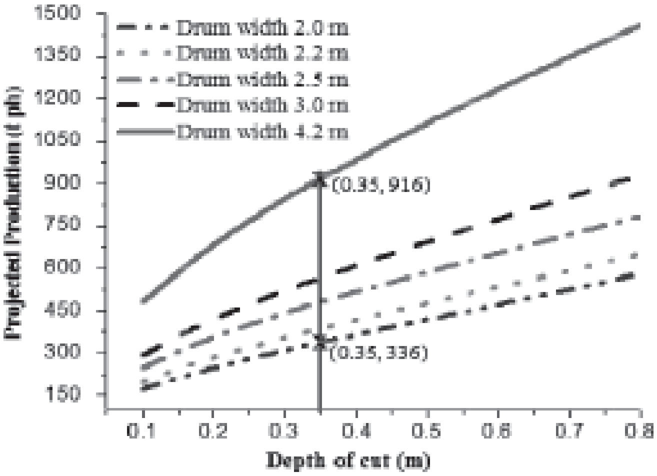

Fig.6 Production with depth of cut on varied drum width at UCS 50 MPa

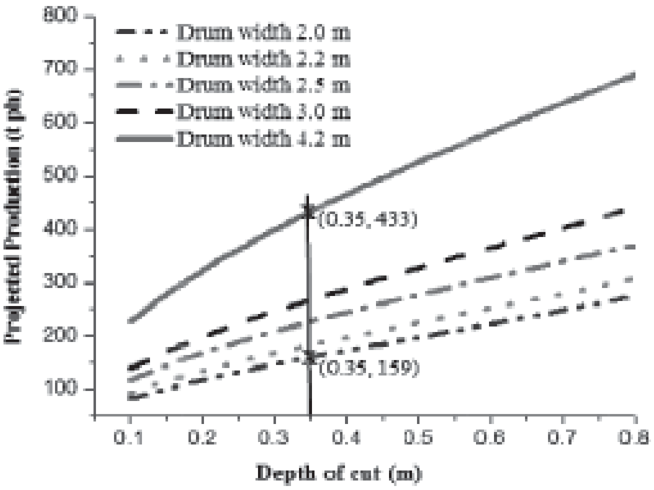

Fig.7 Production with depth of cut on varied drum width at UCS 100 MPa

Production is projected for compressive strength of 15, 30, 50 and 100 MPa as shown in Figs. 4, 5, 6, and 7 respectively. This range of compressive strength has been considered because most the surface miners are being used in this range and furthermore it will help in refined estimation of production.

From the above analysis of production it may be observed that there is a trend change at 0.35m depth of cut. The trend is nonlinear in nature before 0.35 m cutting depth and linear beyond that irrespective of the uniaxial compressive strength of rock being cut. Production decreases with increase in compressive strength of rock for constant depth of cut and drum width.

C. Comparative analysis of cutting performance

Production at minimum and maximum drum width i.e., 2m and 4.2 m respectively, was evaluated and presented in Table IV.

The difference in production with varied drum dimensions decreases with increasing uniaxial compressive strength (one fourth). This is also indicative of lower influence of drum dimension on production achieved in hard rocks. Use of contact area concept may yield better results in production estimation as described in earlier sections.

Table IV. Production analysis with varied drum specifications at average depth of cut of 0.35 m

	UCS(MPa)	Production (tph) at drum width		Production difference(tph)
		2.0(m)	(4.2m)	
1	15	569	1549	980
2	30	454	1237	783
3	50	336	916	580
4	100	159	433	274

D. Prediction of production

It has been observed from the above sections that rock property, i.e., uniaxial compressive strength of rock, machine design and operating parameters, i.e., machine power, width of the drum and depth of cut influence on the production of surface miner immensely. Machine parameters are directly proportional whereas uniaxial compressive strength of rock is inversely proportional to production. Production can be predicted more precisely by considering all these parameters, which can be expressed as :

$$P = \frac{10.75P_O.W.DOC+225.88\sigma_C}{\sigma_C} \qquad \text{... ... 4}$$

Where,

P = production (t/h)

P_o = power (kW)

DOC = depth of cut (m)

σ_c = uniaxial compressive strength (MPa)

The index of determination (R^2) of the above relation is 0.78. Thus, can be considered for realistic production estimation using surface miners.

IV. Conclusions

Middle cutting drum surface miners of various models were studied on different rock types whose uniaxial compressive strength up to a range of 200 MPa. Machine power ranged from 450 to 1194 kW, drum width and drum diameter varied from 2 to 4.2 m and 1.04 to 1.86 m respectively. Maximum depth of cut varies with drum diameter, ranged from 0.25 to 0.8 m. Normalized production was equated to eliminate the influence the drum dimensions. The effect of machine power and depth of cut on production performance of surface miner were analyzed considering the compressive strength. An empirical relation was developed combining both rock and machine parameters to assess the quantum of production. The developed equation can be utilized for computing the power requirement also for a given production. More in-depth investigations are necessary to fine tune the developed equations considering the rock structure, abrasivity and other machine design parameters (the vane spacing, pick spacing, angle of wrap, etc.) and operating parameters (cutting speed, inclination, etc.).

Acknowledgments

The views expressed in this paper are those of authors and not necessarily of the organizations they represent. Facilities extended by Department of Mining Engineering and Mining Machinery Engg., Indian School of Mines, Dhanbad and machine manufacturers, namely, L&T and Wirtgen is thankfully acknowledged.

References

[1] Wirtgen Surface Miners in Operation Around the Globe (2013): Job Report. Website: www.media.wirtgen-group.com.

[2] Ghose, A. K. (2008): New technology for surface mining in the 21 st century – emerging role for surface miners. *Journal of Mines, Metals and Fuels*, 56 (3 & 4), 41-43.

[3] Prakash, A., Murthy,V. M. S. R., and Singh, K. B. (2013): Rock excavation using surface miners: An overview of some design. *International Journal of Mining Science and Technology*, 23, 33-40.

[4] Ghose, A. K., Schimm, B., and Niyogi, S. (2001): New Technology for Surface Mining in the 21st Century-Emerging Role for Surface Miners. Mine Planning and Equipment Selection.

[5] Dey, K., and Bhattacharya, J. (2012): Operation of Surface Miner: Retrospect of a Decade Journey in India. Procedia Engineering, 46, 97-104.

[6] Prakash A. (2013): A study into the influence of intact rock and rock mass properties on the performance of surface miners in Indian geo-mining conditions. PhD thesis, Indian School of Mines Dhanbad.

[7] Wirtgen Surface Mining Manual (2010): Applications and Planning Guide. Website: www.wirtgen.com.

[8] Origliasso, C., Cardu, M., and Kecojevic, V. (2013): Surface Miners: Evaluation of the Production Rate and Cutting Performance Based on Rock Properties and Specific Energy. *Rock Mech Rock Eng*, 47, 757-770.

[9] Jones, I.O., and Kramadibrata, S. (1995): An excavating power model for continuous surface miners. Ausimm Proc, 300 (2), 33-40, ISSN : 1034-6783.

[10] Prakash, A., Murthy, V. M. S. R., and Singh, K. B. (2013): Performance simulation of surface miners with varied machine parameters and rock conditions: some investigations. *Journal of Geology and Mining Research*, 5, 12-22.

[11] Roxborough F.F., and Pedroncelli, E.J. (1982): A practical evaluation of some coal cutting theories using a continuous miner. *Min Eng.*

AUTOMATION OF UNDERGROUND COAL MINES USING PLC

(Continued from page 180)

[18] www.nfiautomation.org/FREE_Download/Technical%20Documents/PLC/Basics_of_PLC_Programming.pdf, dated 5 August, 2015.

[19] www.sarlatech.wordpress.com/2011/06/06/mining-industry-increased-automation-increased-work-force-safety/, 14 August, 2012.

[20] www.web.iitd.ac.in/~suniljha/MEL334/PLC_Basics.pdf, dated 3 May, 2013.

[21] www.dgms.gov.in/pdf/news/DGMS%20STRATEGIC%20PLAN%202011.pdf, DGMS strategic plan 2011-15, dated 14 April, 2015.

[22] www.ipcc-nggip.iges.or.jp/public/gp/bgp/2_7_Coal_Mining_ Handling.pdf, dated 6 May, 2013.

[23] Chaulya S. K., Bandyopadhyay L. K., and Mishra P. K. (2008): Modernization of Indian coal mining industry: Vision 2025, Journal of Scientific & Industrial Research, 67: pp. 28-35.

[24] Kumar A., Kingson T. M. G., Verma R. P., Kumar A., Mandal R., Dutta S., Chaulya S. K. and Prasad G. M. (2013): Application of gas monitoring sensors in underground coal mines and hazardous areas, *International Journal of Computer Technology and Electronics Engineering,* 3(3): 9–23.

[25] www.ampcontrolgroup.com/sites/default/files/projects/brochures/gas_detection_system_0.pdf, dated 24 May, 2015, A case study on Gas ventilation monitoring and control system.

[26] Slattery C., Hartmann D. and Ke L. (2009): PLC evaluation board simplifies design of industrial process-control systems, Analog Dialogue, 43(2): pp.3-10.

[27] Bandyopadhyay L. K., Chaulya S. K., Dutta M. K., Narayan A. and Kumar M. (2005): Development of an environmental monitoring system for underground coal mines. Proceedings of International Seminar on Coal Science and Technology – Emerging Global Dimensions (eds. Singh A. K. and Sen K.), Allied Publishers, New Delhi, India, pp. 629–635.