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# Performance simulaton of surface miners with varied machine parameters and rock conditions: Some investigations

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**Application of surface miners is gaining popularity in different surface mines of India due to the wide range of advantages offered by them. More than 100 surface miners are operating in India in different coal, limestone and bauxite mines today. For new start-ups, however, it is imperative to select appropriate specifications of surface miner considering the rock/rockmass properties for a given production target and chip size. The emphasis of this paper is on performance estimation of different available models of surface miner with varied machine parameters and rock conditions for facilitating the selection of a particular model for a given production requirement. From the review of literature, it was found that the specific energy required to cut the rock is predominantly influenced by uniaxial compressive strength of rock and the same can be determined through laboratory investigations. The current study envelops the development of an approach for the estimation of theoretical production capacity of surface miner along with simulation studies for achieving a particular cut size. The theoretical production capacity of a few surface miners, based on their respective specifications was analysed and found to range from 264 to 5865 $m^3$/h for the chip size varying from 50 to 175 mm. The suggested approach can be useful to draw appropriate specifications of surface miner for a given production. Instantaneous cutting rate was observed to be high for rock strength less than 50 MPa. Pick consumption was also arrived at in different mines. The suggested approach was also illustrated with a case study followed by validation.**

**Key words:** Surface miner, picks, cutting drum, specific energy, pick penetration.

## INTRODUCTION

Surface miners of various make brand and specifications are being used for mining of minerals world-wide. The application of surface miners corroborates in soft to medium hard rock with compressive strengths ranging up to 120 MPa (Ghose, 2008). Improved product size, pick life, reduced power consumption and higher productivity are the principal objectives of improving cutting performance of surface miners. Pick consumption is one of the key and regular problems faced during production.

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Increased pick consumption hampers production and, in turn, economy of mining. The increase in pick consumption with production enhancement as observed in different Indian coal and limestone mines is shown in Figures 1 and 2. Pick breakage usually takes place when the cutting force, that is, exceeds the pick strength while attempting for higher production. The actual production rate for minimum pick consumption needs to be decided based on rock properties. Improper synchronisation of machine operation namely haulage/cutting speed, rpm and depth of cut with rock properties often lead to either pick breakage (Figure 3) or wearing of pick (Figure 4).

This can be reduced by operating surface miner at a suitable speed based on rock/rock mass properties

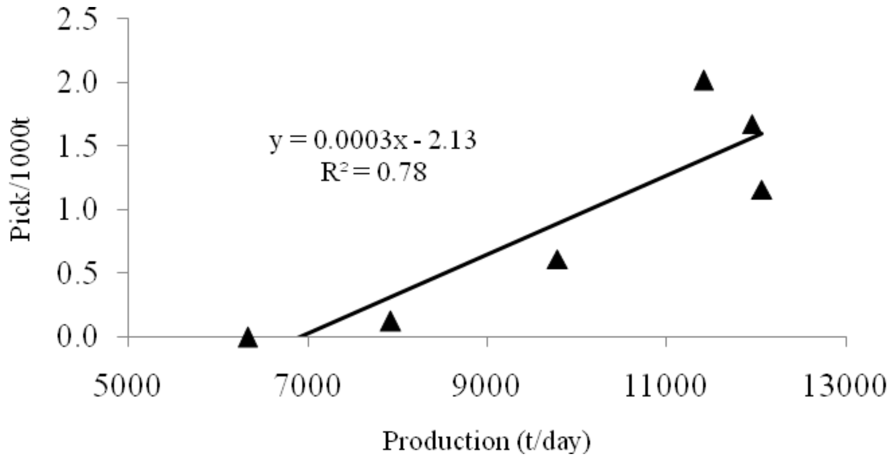


**Figure 1.** Relation between coal production per day and pick consumption, India.

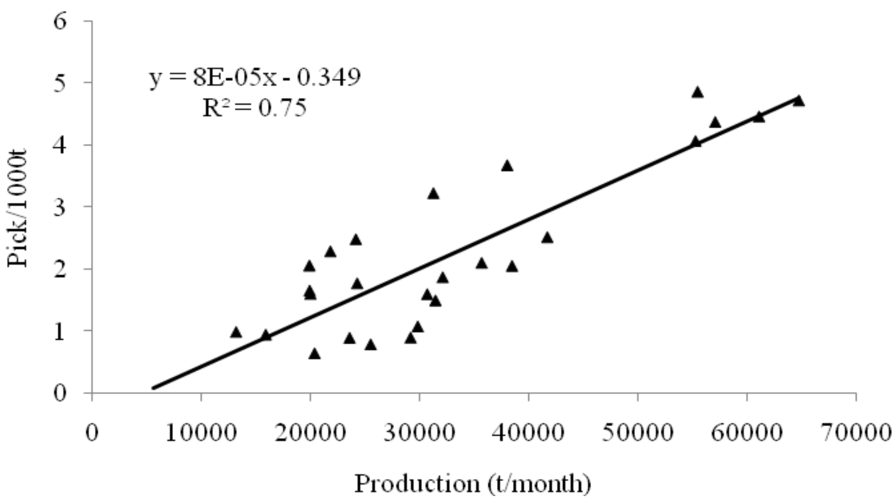


**Figure 2.** Relation between limestone production per month and pick consumption, India.

without overloading the picks. Minimum cutting force required for a particular penetration depth can be obtained by proper pick configuration and attack angle which can be analysed through laboratory tests. It may be seen from the above regression analysis that the pick consumption has a good dependency on the production achieved, may it be coal or limestone.

## MATERIALS AND METHODS

### Cutting capacity estimation of surface miner

Contribution of each pick to the cutting process can be seen in relation to that of neighbouring picks as the drum rotates and advances into the mineral. The design should be made in such a way that the areas removed by the picks are sensibly equal and no pick is over loaded or underutilized (Anon, 1984). Total number of picks attacking at a time depends on area of the cutting drum in contact with the rock, that is, product of drum arc length (La), drum width (W) and pick spacing. The arc length in contact with rock (Figure 5) is expressed as:

$$La = \frac{2\pi R\cos^{-1}\left(\frac{R-D}{R}\right)}{360} \qquad [1]$$

Where, La = length of arc of drum in contact with rock (m), R = drum radius (m) and D = depth of cut (m).

The length of arc depends on depth of cutting. Equation (1) was formulated by the authors based on various drum design specifications available, holds good for depth of cut less than radius of drum. Haulage speed of surface miner is under the control of operator for a constant rotational drum speed which ranges from 60 to 100 rpm. The haulage speed determines the product size. It is necessary to know the cutting speed of surface miner for the


**Figure 3.** Broken pick due to overload.

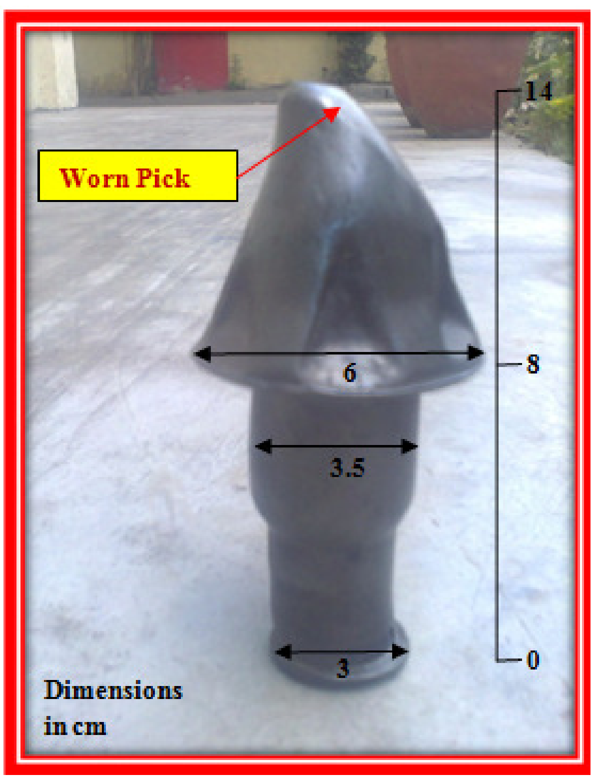


**Figure 4.** Worn pick due to rock abrasivity.

desired product size of ore/mineral. The cutting speed depends on two movements namely, linear motion of the surface miner and rotational motion of cutting drum. The size of the chip is proportional to the tool advance per revolution. Production depends on the cutting area of the drum in contact with the rock and is calculated as:

$$P = HS \text{ x } CA \quad [2]$$

Where, P = production ($m^3$/hr) and CA = contact area of drum with rock ($m^2$).

The concept of desired haulage speed (HS) was well documented by various authors (Brooker, 1979; Ghose and Murthy, 1989) for shearer. The same model has been applied for surface miner, expressed as:

$$HS = \frac{TAR \text{ x } DS}{1000} \quad [3]$$

Where, HS = haulage speed (m/min), TAR = tool advance per revolution (mm) and DS = drum speed (rpm).

Maximum size of cut material will be equivalent to pick advance after each revolution, represented as P in Figure 5. The contact area relies on the drum dimension, that is, width of the drum and the length of arc coming in contact with the rock, which is expressed as:

$$CA = La \text{ x } W \quad [4]$$

Where, La = length arc of drum in contact with rock (m) and W = drum width (m).

Various models of surface miner have varying drum specifications and consequently affect the contact area of drum with rock. Specifications of a few models are presented in Table 1. The haulage speed for achieving 50 mm chip size at 60 rpm drum speed is calculated from Equation 3.

HS = 50 x 60/1000 = 3 m/min

The theoretical production is calculated from Equation 2 as given:

P = 3 x 1.47 x 60 = 264.9 $m^3$/h

Similarly, haulage speed and theoretical production are calculated for different chip sizes at vary drum speed.
Following assumptions were made for simulation of machine performance:

a. Production has been calculated under ideal condition that is, with 100% efficiency, hence considered to be theoretical,
b. Rock/rock mass parameters are not included for calculating the machine performance,
c. Pick spacing has been assumed to be expedient enough to have chip size less than or equal to tool advance per revolution, so that maximum chip size will form in the direction of cutting.

## SIMULATION OF PERFORMANCE

### Selection of operating parameters

The haulage and drum speed can be varied for obtaining

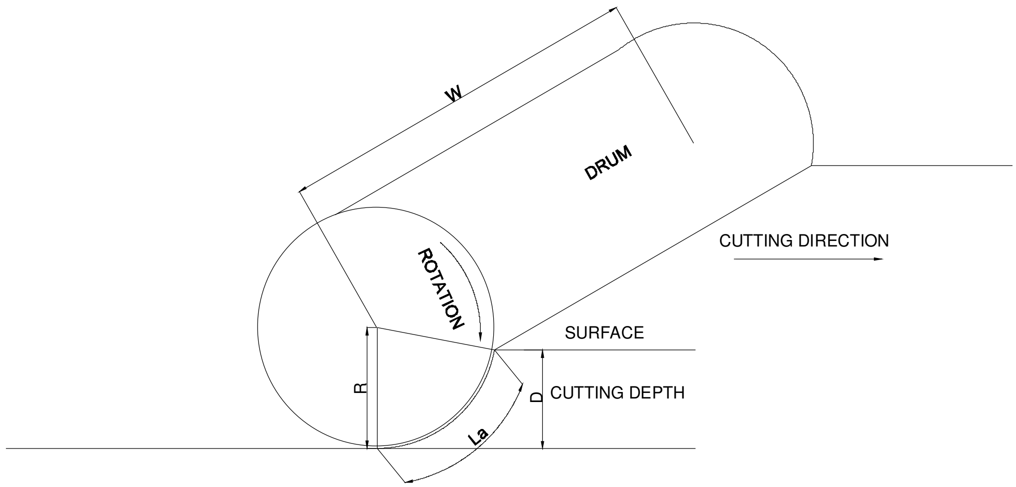


**Figure 5.** Length of arc of drum in contact with the rock during cutting operation.

**Table 1.** Model specification of a few surface miners.

| Specifications | Model A (2200SM) | Model B (2500SM) | Model C (3700SM) | Model D (4200SM) |
|---|---|---|---|---|
| Cutting depth (m) | 0.35 | 0.60 | 0.60 | 0.80 |
| Drum radius (m) | 0.57 | 0.70 | 0.70 | 0.93 |
| Drum width (m) | 2.20 | 2.50 | 3.70 | 4.20 |
| Contact length, La (m) | 0.67 | 0.99 | 0.99 | 1.33 |
| Contact area ($m^2$) | 1.47 | 2.49 | 3.69 | 5.58 |

desired chip size and the theoretical production. The efficiency of the machine relies on technology of machine design and rock/rock mass parameters. Therefore, machine efficiency, that is, energy transfer ratio from cutting head to rock formation has to be taken into account for estimating actual production and, in turn, selecting suitable surface miner. The estimated production for varying drum speed (60 to 100 rpm) in different surface miner models (A, B, C and D) is graphically depicted in Figures 6, 7, 8 and 9, using Table 1 and Equations 1, 2, 3 and 4. The length of drum arc in contact with the rock is calculated by Equation 1 and its product with drum width (Equation 4) imparts contact area as given in Table 1.

Theoretical production capacity of a few surface miners and chip size were analysed, based on their respective specifications, and the same ranged from 264 to 5865 $m^3$/h for the chip size from 50 to 175 mm. For the above production capacity and chip size, simulation has been carried out to arrive at two important machine operating parameters, namely, cutting speed and drum rpm.

## Specific energy

The number of picks attacking rock at a time depends on depth of the cut. The number of picks per attack depends on cutting force required and, in turn, the specific energy required by each pick to cut the rock of suitable penetration depth (Figure 10). Laboratory investigation is necessary to determine proper penetration depth with minimum specific energy consumption (Bilgin et al., 2006) since depth of penetration and pick spacing depends on rock properties. If the line spacing is too close, the cutting is not efficient because the rock is over crushed; in this case, tool wear is also high due to high friction between tool and rock, as demonstrated by Johnson and Fowell (1986). Pick spacing can be designed as shown in Figure 11 by laboratory tests.

One of the most accepted methods to predict the cutting rate of any excavation machine is to use cutting power, specific energy obtained in laboratory and energy transfer ratio from cutting head to rock formation as given in the following equation (Rostami and Ozdemir, 1994; Rostami et al., 1994):

$$ICR = \frac{kP}{SE_{opt}} \quad [5]$$

Where, k = energy transfer ratio, P = cutting power of cutting head (kW) and $SE_{opt}$ = optimum specific energy/

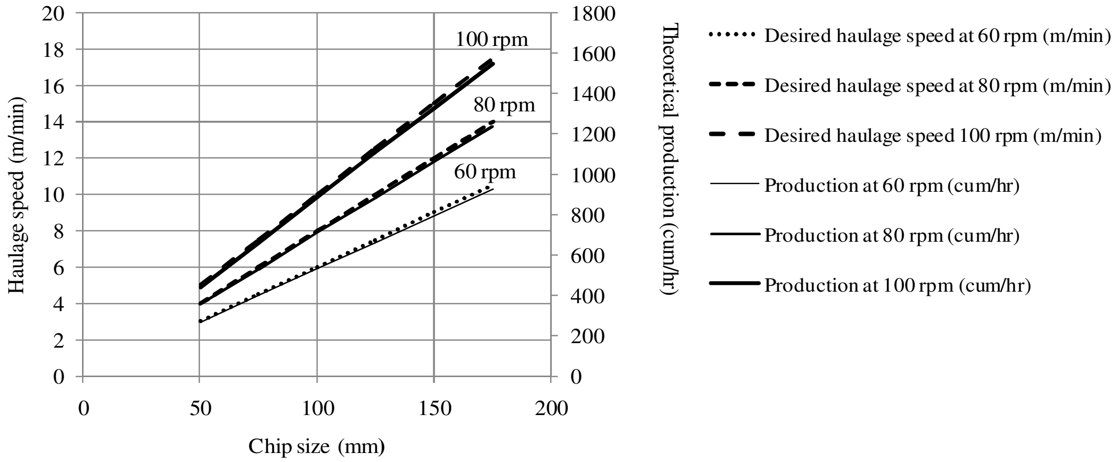


**Figure 6.** Haulage speed and drum speed for desired theoretical production and chip size (Model A).

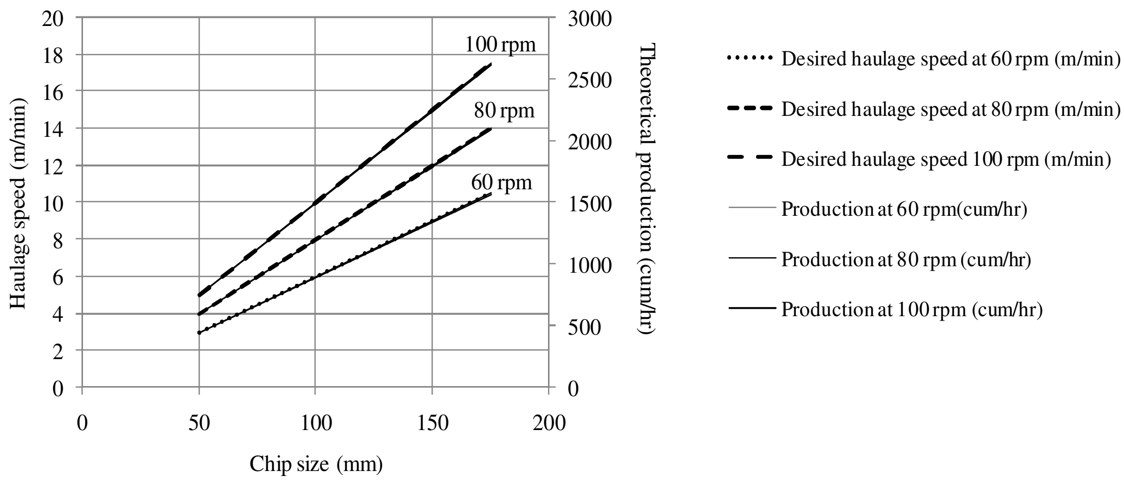


**Figure 7.** Haulage speed and drum speed for desired theoretical production and chip size (Model B).

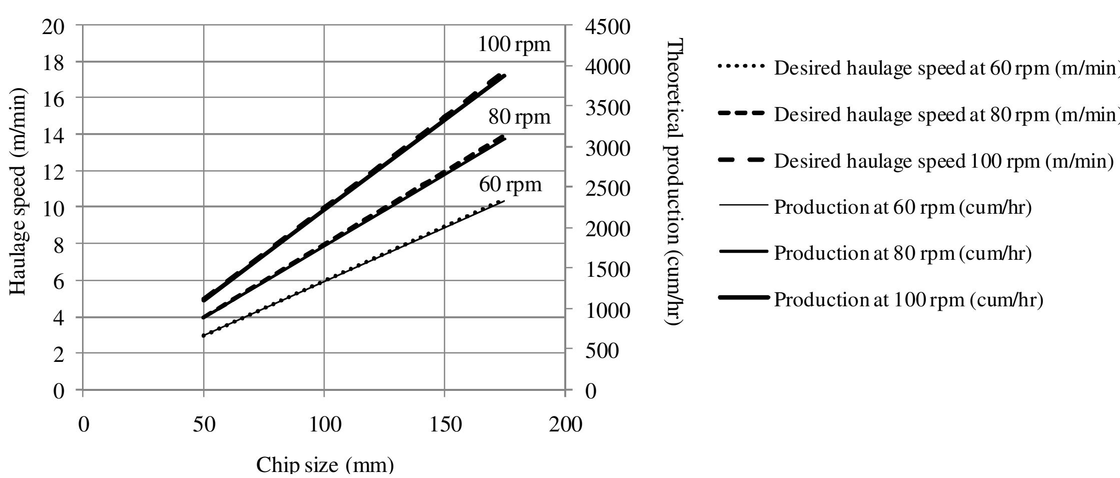


**Figure 8.** Haulage speed and drum speed for desired theoretical production and chip size (Model C).

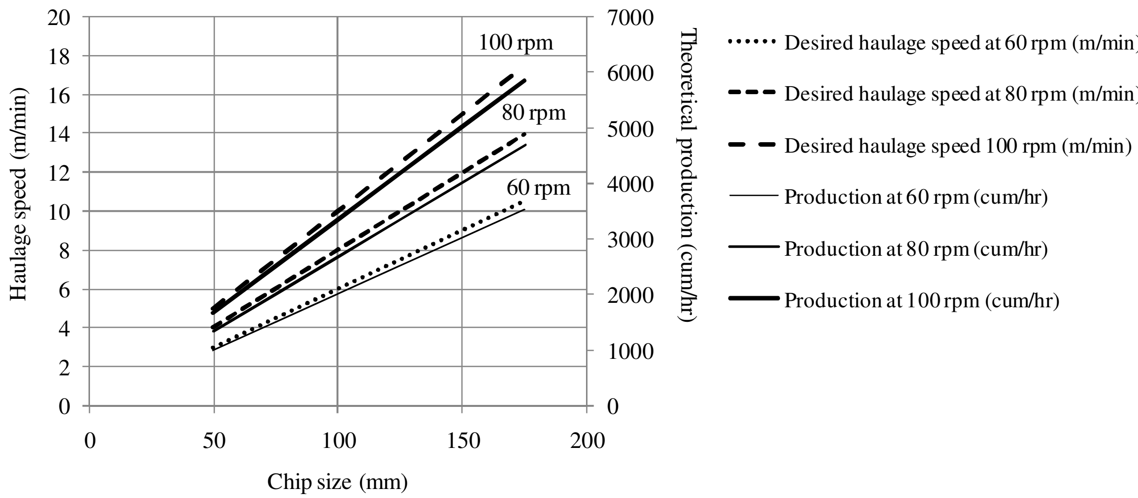


**Figure 9.** Haulage speed and drum speed for desired theoretical production and chip size (Model D).

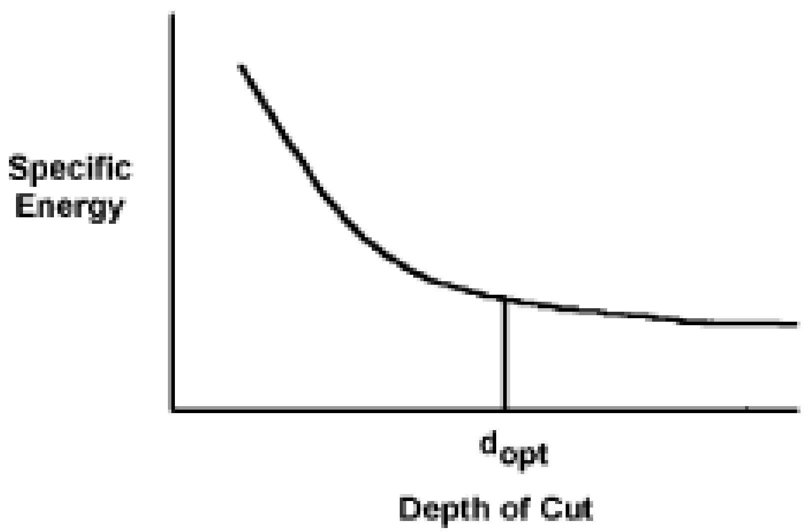


**Figure 10.** Specific energy consumption with varying penetration depth (Bilgin et al., 2006).

pick (kWh/m$^3$).

Rostami and Ozdemir (1994) pointed out that k changed between 0.45 and 0.55 for roadheaders and from 0.85 to 0.90 for TBMs (Tunnel Boring Machine). Production rate and specific power consumption are affected by reducing drum speed or increasing pick penetration. Lower dust level and decreased specific power consumption are the most noticeable benefits of reduced drum speed. Reduction of 35% in overall specific energy between higher and lower speeds (Figure 12) was observed in the previous studies (Ludlow and Jankowksi, 1984).

Laboratory tests were conducted by various authors (Asbury et al., 2001; Balci, 2009; Tiryaki and Dikmen, 2006; Bilgin and Shahriar, 1988; Roxborough and Sen, 1986; Morrell et al., 1970; Snowdon et al., 1982) to determine a relation between specific energy consumption and uniaxial compressive strength while studying the performance of tunnel boring machines, roadheaders, impact hammers and continuous miners. Tests were conducted mainly on coal, shale, limestone and sandstone. It was observed that roadheaders, impact hammers and tunnel boring machines were used in rocks with higher UCS.

The specific energy was also found to be proportional to the cutting force required as expressed by various authors (Asbury et al., 2001; Tiryaki and Dikmen, 2006; Hagan, 2009; Bilgin et al., 2006). By aggregating the

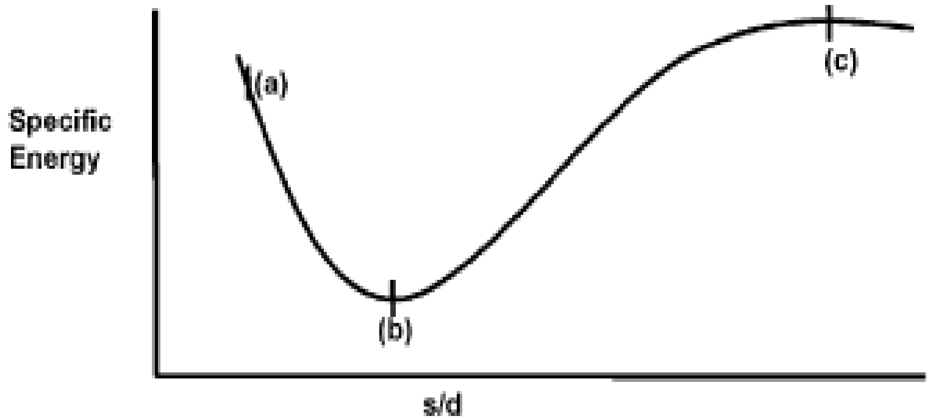


**Figure 11.** Specific energy behaviour with pick spacing to depth ratio (Bilgin et al., 2006).

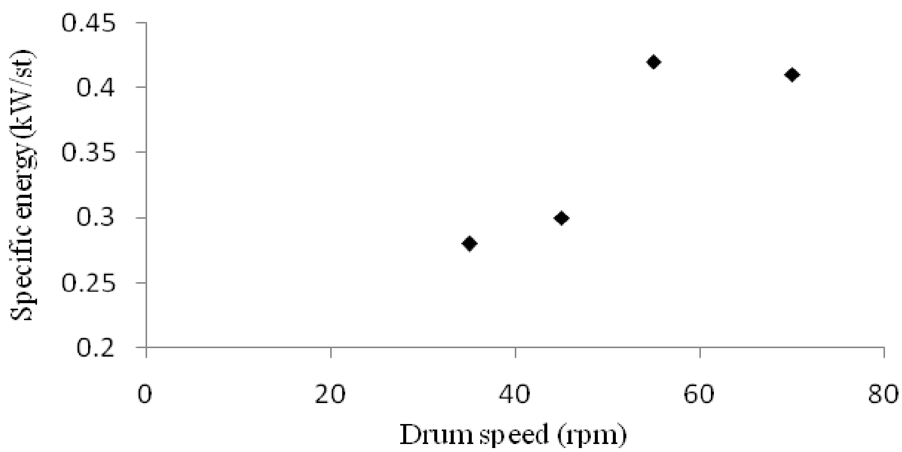


**Figure 12.** Variation of specific energy with drum speed (Ludlow and Jankowksi, 1984).

data generated by different researchers as mentioned above, two generalised equations governing specific energy were derived as given in Figures13 and 14. The relation generated from Figures 13 and 14 are equated as:

$$SE = 0.123\sigma_c + 0.97 \quad (R^2 = 0.81) \qquad [6]$$

$$SE = 2.286F_c + 9.75 \quad (R^2 = 0.79) \qquad [7]$$

Where, $F_c$ = cutting force (kN) and $\sigma_c$ = uniaxial compressive strength (MPa).

## Prediction of surface miner production potential

Production potential estimation for surface miners based on cuttability of rocks has been done from Equations 5 and 6 discussed earlier and the engine power of few models of surface miners (Table 2).

Specific energy was calculated from Equation 6 by varying compressive strength from 30 to 150 MPa. Considering an ideal condition, that is, assuming energy transfer ratio as 1, instantaneous cutting rate (ICR) for different surface miners, as mentioned in Table 2 was determined from the specific energy consumption at varying compressive strengths (Equation 5), and is given in Figure 15a and b, respectively.

It was observed that the instantaneous cutting rate of Model J is the highest compared to other models due to high engine power. In general, instantaneous cutting rate is high for rock strength less than 50 MPa. Though, the manufacturers claim to have cuttability capacity up to 80 MPa, it has been observed in various studies, as discussed in the previous section, that if the compressive strength of rock exceeds 50 MPa, productivity of surface miner is significantly affected. Cutting teeth become worn out very quickly and require frequent replacement.

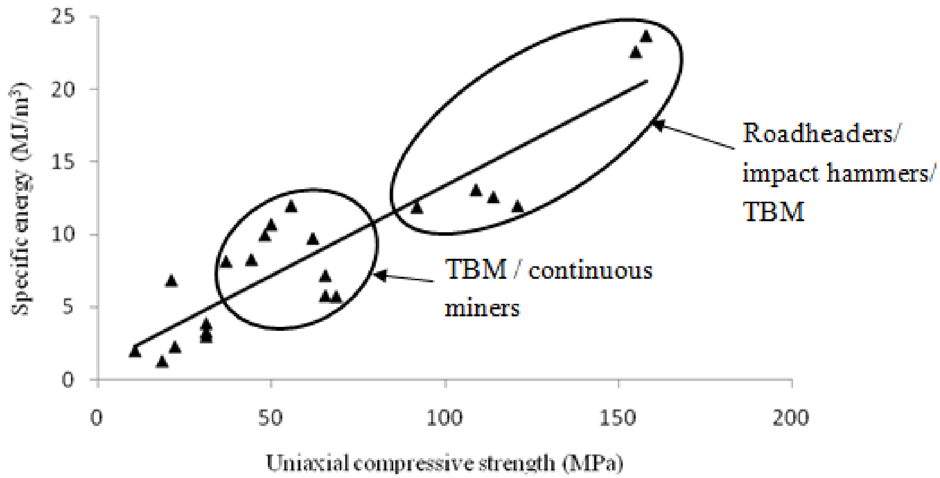


**Figure 13.** Specific energy variation with uniaxial compressive strength in different rocks.

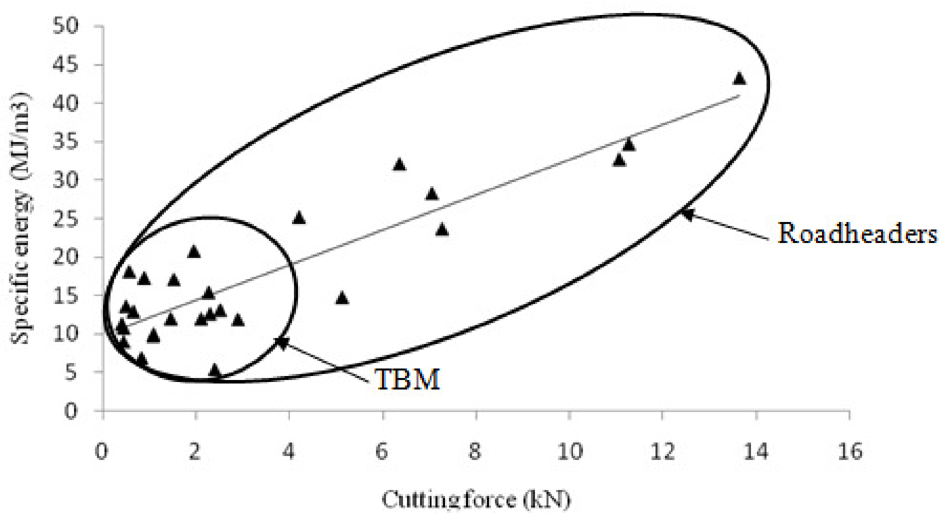


**Figure 14.** Relation between specific energy and cutting force.

However, while selecting a surface miner for a given production target in real life, efficiency of the machine should be taken into account. Also, the performance estimation (ICR) of surface miner needs field evaluation so as to further refine the generalised design approach discussed in the paper.

## Field validation

Model A surface miner was used at Sonepur Bazari open cast mine of Eastern Coalfields Limited, West Bengal. The average uniaxial compressive strength of the coal was 30 MPa. The actual performance of the machine is given in Table 3 and the average chip size produced is shown in Figure 16.

The theoretical production estimated for this model is shown in Figure 6. The actual production, based on tangible working condition and machine efficiency which relies on rock strength, is expressed as:

$$P_a = \eta \text{ x } P_{th} \text{ x } \frac{\text{Actual depth of cut}}{\text{Maximum depth of cut}} \quad [8]$$

Where $P_a$ = actual production ($m^3/h$), $\eta$ = machine efficiency (%), $P_{th}$ = theoretical production ($m^3/h$) and

$$P_a = 0.70 \text{ x } 706 \text{ x } \frac{0.20}{0.35} = 282 \text{ m}^3/\text{h}.$$

However, the desired haulage speed of surface miner should have been 8 m/min but in actual, it was 20 m/min which is much more than its capacity for achieving higher

**Table 2.** Engine power of surface miners operating in mines.

| S/N | Surface miner model | Representation | Engine power (kW) |
|---|---|---|---|
| 1 | 2200SM, KSM223, KSM303 | A | 597 |
| 2 | 2500SM | B | 783 |
| 3 | 3700SM, 4200SM | C | 1193 |
| 4 | 2100SM, T1255 | E | 447 |
| 5 | MTS 180 | F | 500 |
| 6 | MTS 300 | G | 750 |
| 7 | MTS 500 | H | 1650 |
| 8 | MTS 800 | I | 2000 |
| 9 | MTS 1250, MTS 2000 | J | 2500 |
| 10 | KSM 304 | K | 895 |
| 11 | SF202 | L | 515 |
| 12 | T855 | M | 281 |
| 13 | T1055 | N | 317 |

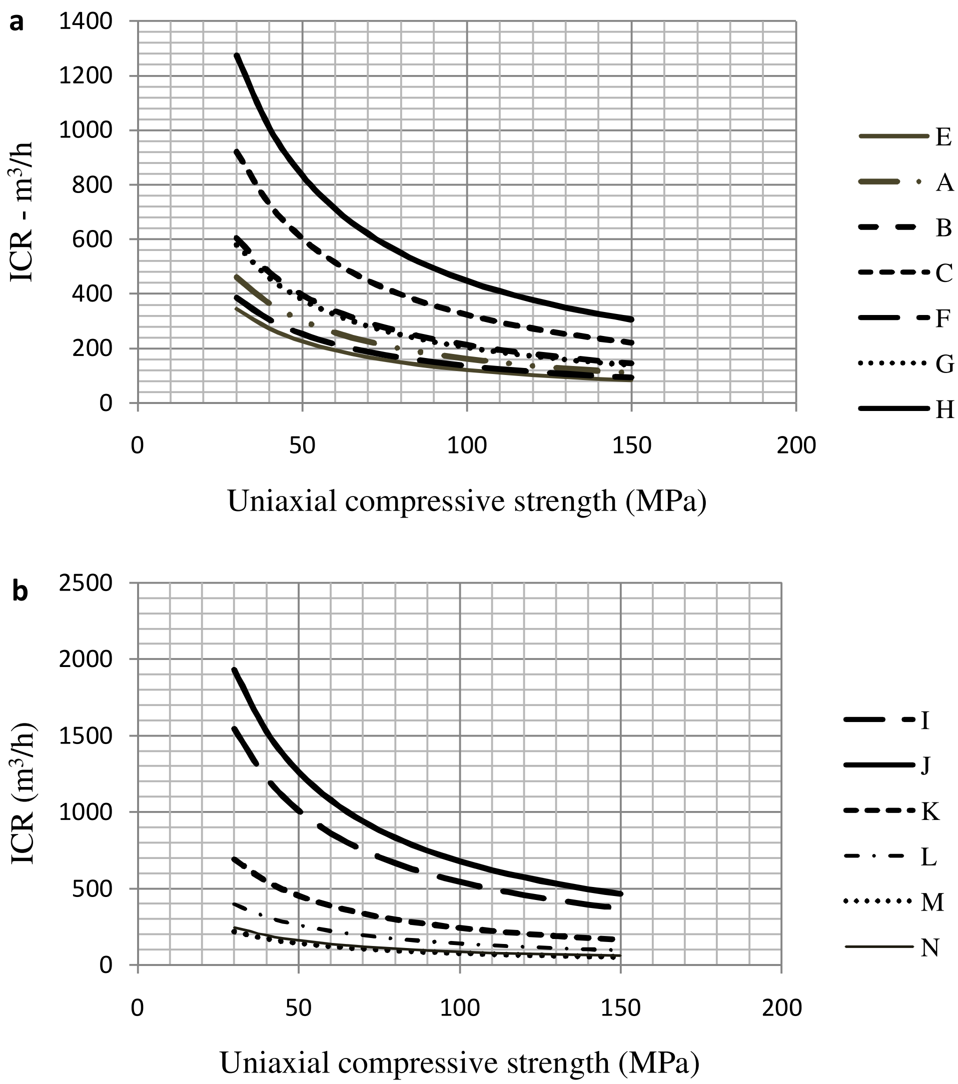


**Figure 15.** (a) Instantaneous cutting rate of surface miners at different compressive strength, (b) Instantaneous cutting rate of surface miners at different compressive strength.

**Table 3.** Actual performance of model A surface miner at Sonepur Bazari, ECL, India.

| Parameter | Values |
|---|---|
| Drum rotation speed (rpm) | 80 |
| Depth of cut (m) | 0.20 |
| Average chip size (mm) | 100 |
| Production ($m^3$/h) | 543 |
| Haulage speed (m/min) | 20 |
| Working hours/day | 14 |
| Pick consumption/day | 5 |
| Machine efficiency (%) | 70 |

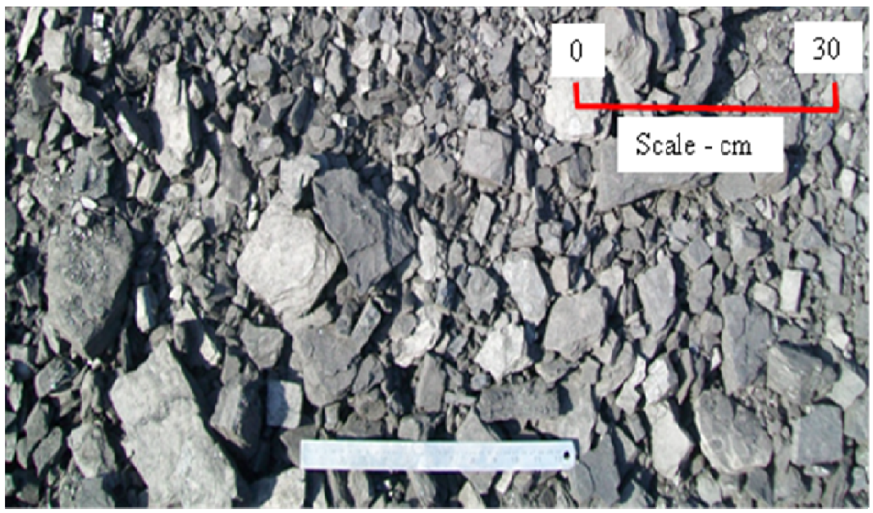


**Figure 16.** Chip size of coal produced at Sonepur Bazari by model A surface miner.

production. The average pick consumption was 5 per day due to the higher cutting speed adopted.

ICR of model A surface miner for 30 MPa UCS, as per Figure 15a is 430 $m^3$/h. The energy transfer ratio is around 0.5 for roadheader and the same has been considered for the surface miner. Thus, the operational cutting rate (OCR) becomes 215 $m^3$/h. In contrast the actual production capacity ($P_a$), based on machine specification as arrived from Figure 6, is 282 $m^3$/h which is 31% higher than the optimum. Thus, there is a need to reduce the production capacity for avoiding the negative impacts such as pick and diesel consumption, machine vibration, dust etc.

## Conclusion

Surface miner should be operated based on its rated specifications. Overworking the surface miner for higher production with disregard to rock strength often results in excessive pick and diesel consumption, machine vibration, dust etc. Replacement of broken or worn out picks is a must for improved cutting efficiency as worn out picks grind the surface instead of cutting. Production can be optimised by controlling haulage speed of surface miner with respect to rock properties. As rock properties play a key role, extensive laboratory and field testing are imperative to determine rock/ rock mass properties. This is necessary to achieve the required size of rock/mineral, for a suitable drum design and operational parameters. Specific energy consumption in rock cutting is linearly related to its uniaxial compressive strength and cutting force. The theoretical production capacity of a few surface miners studied, based on their respective specifications, ranged from 264 to 5865 $m^3$/h for the chip size varying from 50 to 175 mm.

Instantaneous cutting rate which depends on engine power is high for rock strength less than 50 MPa, that is, it is suitable for excavating soft to medium hard rocks. Site specific rock properties other than compressive strength will always be beneficial for precise selection of surface miner. The performance of surface miner needs field evaluation to refine the value of energy transfer ratio, generalised design and selection methodology suggested.

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## REFERENCES

Anon (1984). Computer aided design of cutting drums, Mining research and development establishment, NCB, November pp. 289-295.

Asbury B, Ozdemir L, Rozgonyi TG (2001). Frustum bit technology for continuous miner and roadheader applications, 6th international symposium on mine mechanization and automation. S. Afr. Inst. Min. Met. pp. 135-139.

Balci C (2009). Correlation of rock cutting tests with field performance of a TBM in a highly fractured rock formation: A case study in Kozyatagi-Kadikoy metro tunnel, Turkey. Tun. Und. Sp. Technol. 24:423-435.

Bilgin N, Shahriar K (1988). The development of a rock cutting rig for rapid excavation systems and its application to Amasra coalfield, Proceedings of 6th coal congress of Turkey May 23-27. pp. 13-28.

Bilgin N, Demircin MA, Copur H, Balci C, Tuncdemir H, Akcin N (2006). Dominant rock properties affecting the performance of conical picks and the comparison of some experimental and theoretical results. Int. J. Roc. Mec. Min. Sci. 43:139-156.

Brooker CM (1979). Theoretical and practical aspects of cutting and loading by shearer drums, Part I, Col. Gua. Coa. Int. January and April. pp. 41-50.

Ghose AK, Murthy VMSR (1989). Power rating of shearers – A microcomputer model, Indian conference on computer application in mineral industry. Min. Geo. Met. Inst. India, Calcutta, Jan. 6-7:41-61.

Ghose AK (2008). New technology for surface mining in the 21st century – emerging role for surface miners, J. Min. Met. Fuels March-April 56(3-4):41-43.

Hagan P (2009). A study on the effect of moisture content on rock cutting performance, Aziz N (ed), Coal: Coal operators' conference, Univ. Wol. Aus. Ins. Min. Met. pp. 340-347.

Johnson ST, Fowell RJ (1986). Compressive strength is not enough, In: Hartman HL, editor, Proceedings of the 27th US rock mechanics symposium. pp. 840-845.

Ludlow J, Jankowksi RA (1984). Use lower shearer drum speeds to achieve deeper coal cutting, Min. Eng. March pp. 251-255.

Morrell RJ, Bruce EW, Larson DA (1970). Tunnel boring technology-disk cutter experiments in sedimentary and metamorphic rocks. Bur. Min. RI 7410:32.

Rostami J, Ozdemir L (1994). Roadheader performance optimization for mining and civil construction, In: DeMers JE et al., editors, Proceedings of the 13th annual technical conference, Ins. Sh. Dri. Tec., Las Vegas, Nevada pp. 12-15.

Rostami J, Ozdemir L, Neil D (1994). Performance prediction: A key issue in mechanical hard rock mining. Min. Eng. November pp.1264-1267.

Roxborough FF, Sen GC (1986). Breaking coal and rock, In: Martin CH (editor), Australian coal mining practice, Australia, Ins. Min. Met. P. 9.

Snowdon RA, Ryley MD, Temporal JA (1982). A study of disc cutting in selected British rocks. Int. J. Roc. Mec. Min. Sci. Geo. Abs. 19:107-121.

Tiryaki B, Dikmen AC (2006). Effects of rock properties on specific cutting energy in linear cutting of sandstones by picks. Roc. Mec. Roc. Eng. 39(2):89-120.