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Technical note—A theoretical comparison of the performance of drag picks in relation to coal-strength parameters

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SYNOPSIS

A theoretical comparison is made between point-attack and wedge-shaped picks in regard to their cutting efficiencies in coals having different strength characteristics.

With specific energy as a criterion of cutting efficiency, it is shown that a mathematical expression can be derived for the assessment of the relative performances of these two groups of picks as a function of coal-strength parameters and pick-tip angle.

The ratio of tensile to compressive strength of coal is found to play a significant role in the determination of relative cutting efficiencies, lower ratios favouring the use of point-attack picks.

SAMEVATTING

Daar word 'n teoretiese vergelyking getref tussen spitspuntige en wigvormige pikke wat betref hul snydoeltreffendheid in steenkool met verskillende sterkte-eienskappe.

Met spesifieke energie as 'n maatstaf van snydoeltreffendheid word daar getoon dat daar 'n wiskundige uitdrukking afgelei kan word vir die evaluering van die relatiewe werkverrigting van hierdie twee groepe pikke as 'n funksie van steenkoolsterkteparameters en die hoek van die pik se punt.

Daar is gevind dat die verhouding van die trek- tot die druksterkte van steenkool 'n beduidende rol speel in die bepaling van die relatiewe snydoeltreffendheid, met 'n laer verhouding ten gunste van die gebruik van spitspuntige pikke.

INTRODUCTION

In modern coal-winning machines, the extraction of coal results from the interaction between the pick and the coal substance. In conjunction with the optimization of cutter heads, the appropriate selection of cutting tools is of paramount importance since they have a substantial influence on machine performance.

Point-attack and wedge-shaped picks are the two main types of drag picks employed on underground-mining machinery, such as continuous miners and shearers. In practice, cutting efficiency, dust generation, mechanical strength of coal, ignition potential, and pick wear are generally accepted as the main parameters that influence the selection of the most appropriate pick.

What is the better type of pick cannot be answered readily. There are pros and cons for both versions. So, it is not surprising to find that there are long-standing conflicting views on the relative merits of point-attack and wedge-shaped picks. Although early laboratory and theoretical findings favoured the wedge-shaped picks, more recent tests[1,2] on the performance of a continuous miner in cutting South African coal have proved that the wedge-shaped pick is a more efficient tool only at shallower depths of cut. At greater depths of cut (generally beyond about 50 mm), the point-attack pick was found to be the more efficient.

A review of the published literature reveals that the magnitudes of coal-strength parameters, where the cutting performance of one particular type of pick would be superior to that of the other, have not been established quantitatively. With this in view, this note attempts to make a simple theoretical analysis of the effects of such strength parameters on the relative performances of point-attack and wedge-shaped picks.

CUTTING EFFICIENCY

The maximum potential excavation rate to be attained from a given excavation machine is represented by its maximum cutting efficiency. Specific energy is the most widely accepted criterion of cutting efficiency. Therefore, in a comparison of picks, it is natural that reference should be made to specific energy.

Specific energy is defined as the amount of work expended in cutting unit volume (MJ/m^3) or unit mass (kJ/t) of material. It can be calculated as follows[3]:

$$SE = F_c \cdot L/Q \qquad [1]$$

where

SE = specific energy,

F_c = mean cutting force on the pick,

L = distance cut by the pick,

Q = volume of material cut.

A theoretical analysis[4] has shown that the same fundamental mode of rock breakage is invoked by both point-attack and wedge-shaped picks. Evans's significant contributions into the mechanics of coal and rock breakage by picks provides a satisfactory understanding of the effects of coal or rock strength, depth of cut, and pick geometry on

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the forces required to cut. Two basic equations developed by Evans[5,6] that are used to predict the cutting forces for a point attack and wedge-shaped pick respectively are as follows :

$$F_p = \frac{16\pi t^2 d^2}{\cos^2\Phi.\,u} \qquad [2]$$

and

$$F_w = 2\,t\,d\,W\,.\,\sin\theta\,/\,1-\sin\theta\,, \qquad [3]$$

where

F_p = cutting force exerted by the cone,
t = tensile strength of material cut,
d = depth of cut,
Φ = semi-angle of cone,
u = uniaxial compressive strength of material cut,
F_w = cutting force exerted by the wedge,
W = width of wedge,
θ = semi-angle of wedge.

Some related cutting geometry parameters are shown in Figure 1 for both types of picks.

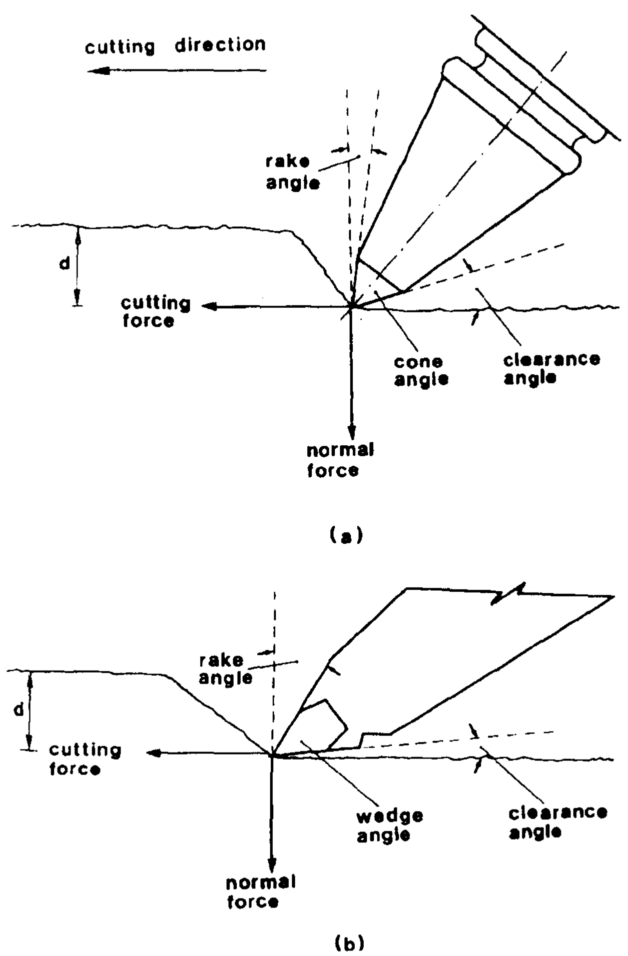

Figure 1—Some cutting geometry parameters of (a) point-attack and (b) wedge-shaped picks

Theoretical cutting forces calculated from equations [2] and [3] are the peak cutting forces at the instant of failure. However, as given in equation [1], in the computation of specific energy, the mean cutting force is used. Experimental results in the literature[3] show that the ratio of peak to mean cutting force can be reasonably accepted as 2 for a wide range of rocks including coal. Hence,

Mean cutting force = 0,5 (peak cutting force). [4]

Equations [2] and [3], which predict cutting force, relate to the operation of a single cutting tool in isolation. In practice, however, an excavation machine uses an array of picks disposed on a drum or a cutter head in which the picks are required to interact. For an array of picks acting on a drum or a cutter head, Evans[5] has postulated the condition (Figure 2) where wedge-shaped picks will cut the same volume of material as point-attack picks, which is given by

$$W \simeq 1{,}5d\,, \qquad [5]$$

where W = width of wedge and d = depth of cut.

Since a low consumption of specific energy implies a high efficiency, the condition for a point-attack pick to have an equal or superior cutting efficiency to that of a wedge type can be written as

$$SE_p \leq SE_w\,, \qquad [6]$$

where SE_p and SE_w are the specific energies for point-attack and wedge-shaped picks respectively. Following the principles given in equations [1] and [4], under equal breakage conditions, and with the substitution of equation [5] into equation [3], it is possible to rewrite equation [6] as

$$\frac{16\pi t^2 d^2(L)}{2(\cos^2\Phi.\,u)Q_p} \leq \frac{2td(1{,}5\,d)\sin\theta(L)}{2(1-\sin\theta)Q_w} \qquad [7]$$

with the additional notations of Q_p and Q_w, which are the volumes of coal cut by point-attack and wedge-type picks respectively, Q_p being equal to Q_w in this case.

In a comparison of these two generic groups of picks, an approximation made by Evans[5] can be followed, in which it is accepted that it is appropriate to have equivalent tip angles (cone angle = wedge angle). Thus, since $\Phi = \theta$,

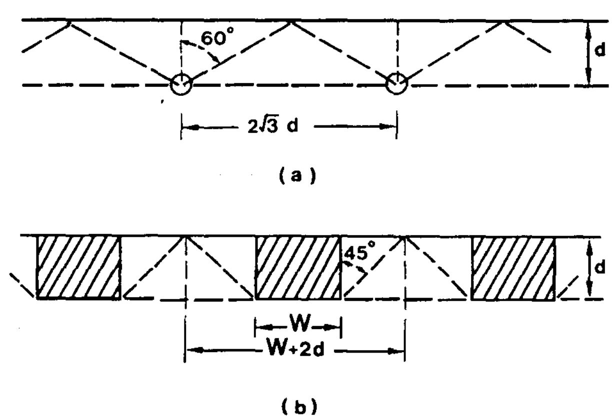

Figure 2—Equal breakage by (a) point-attack and (b) wedge-shaped picks, after Evans[5]

equation [7] can be simplified into

$$t/u \leq 0{,}06(1 + \sin\theta)\sin\theta. \qquad [8]$$

The practical outcome of this analysis is that the cutting efficiency of point-attack picks will be superior to that of wedge-shaped picks when the condition in equation [8] is satisfied. In other words, the relative cutting efficiency of the picks will be a function of the tensile-to-compressive strength of coal and the tip angle.

Using equation [8], theoretical efficiency ranges of point-attack and wedge-shaped picks are shown in Figure 3. It can be followed from Figure 3 that, in zone A, point-attack tools will give better cutting performance than wedge-type tools because of their relatively lower consumption of specific energy. This could be an interesting point for both operating engineers and machine designers, in that point-attack picks are not used on some coal-cutting machinery for the reason that they create more dust and fines than wedge-shaped picks. However, in the general field of rock excavation, it has been proved that minimum specific energy usually produces the maximum size distribution in the cut material. Thus, in conditions that favour point-attack picks from the standpoint of specific energy, an improvement in coal size should also be expected.

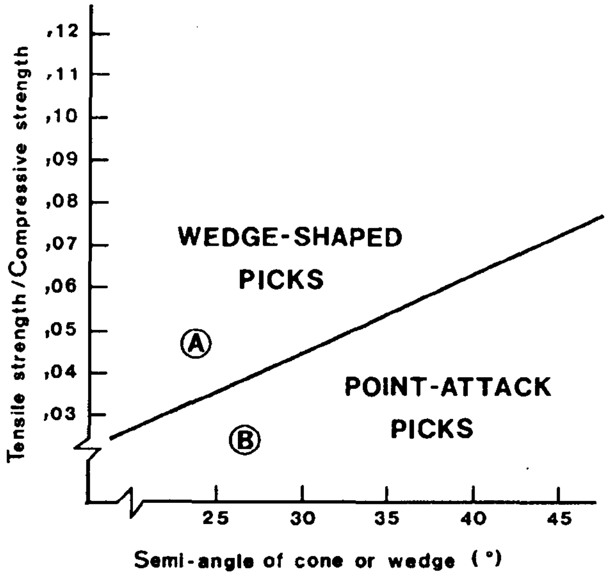

Figure 3—Theoretical cutting-efficiency ranges of point-attack and wedge-shaped picks under equal breakage conditions

Unfortunately, Figure 3 cannot be directly applied to the selection of suitable cutting tools because the laboratory-determined strength parameters of coal ignore discontinuities such as bedding planes, cleat, and other induced fractures. Such discontinuities and load from overburden influence the *in situ* strength and elastic properties, all of which calls for a judgement on their probable effects.

Nevertheless, it is possible to conclude that point-attack tools should perform better when cutting coals that have relatively higher elasticity, since low ratios of tensile-to-compressive strength are associated with elastic, brittle materials.

CONCLUSION

This note has dealt with a theoretical approach to the analysis of the relative cutting performances of the two basic types of drag picks in relation to coal-strength parameters.

Using some fundamental rock-cutting theories, it has shown that a quantitative assessment of the cross-over points between point-attack and wedge-shaped picks can be made in terms of tip-angle and coal-strength parameters. Of the coal-strength parameters, the ratio of tensile to compressive strength is found to govern the relative cutting efficiencies of the pick types considered.

In spite of the assumptions made, it is hoped that this simple analysis provides a contribution to the design and operation of coal-cutting machinery.

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