Analysis of the Cuttability of Coal for Continuous Miner

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***Abstract*—In this paper a practical approach is presented to analyse the coal cuttability of continuous miner due to cutting action of a tool bit. An experiment was performed on the shaper machine using conical tool bit to simulate the cutting action of the tool bit of the excavating machines. Cutting parameters like depth of cut and attack angle were varied and its effect on the amount of coal removal was observed for the efficient cuttability of the mechanical excavator.**

***Keywords—* Conical tool bit; Depth of cut; Attack angle; Material removal rate; Protective geometry**

I. Introduction

The continuous mining machines which were introduced in the 1950's, now account for more than half the production of coal from underground mines. Unfortunately, these continuous miners, which were designed for increasing productivity, have also increased the concentration of respirable dust in the mines. Improving the fragmentation process by understanding the mechanisms of coal/rock breakage will not only reduce respirable dust at the face, but it will also decrease the amount of respirable dust that is liberated during the secondary handling such as loading and transportation etc. The fragmentation process in coal/rock is affected by the following parameters: (1) machine operating parameters (primary factor), (2) in-situ condition, and (3) physical and mechanical properties of coal/rock (secondary factors). The present-day continuous miners are powerful in terms of rated power but are still plagued by wear of bits which hinders development and production as the bits have to be continuously changed at regular intervals. This paper discusses about the overall aspect of bit wear and its effect on the fragmentation of rock. Using the laboratory model set up, numerical models and field testing, a new bit was analyzed to evaluate their performance under different conditions. The results proved that a newer bit design was successful in limiting the amount of wear as well as improving the performance of the continuous miner and production.

From the earliest introduction of coal-cutting machines, their efficiency has left considerable room for improvement. However, this was not highlighted until efforts were made to broaden the application of the first mechanized longwall installations in Europe by the use of machines such as ploughs and shearers. In particular, the introduction of the German-invented coal plough into British mines after World War II revealed serious inadequacies in its ability to handle the generally stronger British coals [1]. There are several key publications, each of which represents a significant contribution to our knowledge of the mechanics of coal breakage by pick. Evans's model of wedge penetration into coal provides a good theoretical understanding of the effects of coal strength, depth of cut, and picks geometry on the forces required to cut [2, 3], and the results of Pomeroy's laboratory coal-cutting experiments established certain principles that are claimed to be fundamental to the design of an efficient coal-cutting system [4, 5].

Despite the widespread availability of such useful information, surprisingly little practical use has been made of it. Large pick drums were designed for longwall shearers based on these principles [6], but it had only limited application and success. Similarly, parallel work undertaken in England [7] led to the development of a novel type of longwall plough, which also had limited but, in this case fairly successful, application [8, 9].

Shearer, continuous miner, road headers are the few of the mechanical excavators who have found their wider application in excavation field for higher rate of production. Tool bits are the important part of these machines and there operational life and cutting parameters associated with them have great impact on the performance of these machines.

Wear of tool bit

Tool Bit wear can be defined as the removal of material from the surface as a result of mechanical action. The mechanism of bit wear can be adhesion, abrasion, oxidation, or diffusion depending on cutting conditions. Chain saw machines, surface miner, continuous miner, shearer, plough etc. are used for coal cutting. In order to increase the daily production it is required to have high machine feed rate and minimal tool changes which demands for powerful machines and high quality tools. Only picks of the highest quality, which are closely adapted to the machine and application, can guarantee a long service life and flawless rotation. Problems encountered by the continuous miners during cutting operations are as follows:

1. Wear of bits of continuous miner.
2. Increase in downtime of the continuous miner and their inability to cut rock partings.
3. The ridges formed during cutting by the continuous miner pose a safety hazard, increasing ignition and dust generation.

Even though bit wear has been recognized for its detrimental effects on cutting efficiency of underground coal mining systems for a long time, the success in controlling wear is far from satisfactory. Undoubtedly, the lack of a complete understanding of the different mechanisms responsible for the wear of the bit makes it difficult to design a better bit. One of the reasons for the difficulty in understanding wear lies in the limitations of the experimental approach. However, a complete study of the wear should consider the effect of the bit design. The occurrence of wear is dependent on numerous parameters which are difficult to be observed in any experimental approach. Heat generation during cutting is considered to be a major factor in advancing the process of wear of bits. During the process of cutting, bits interact with different material having different strength and frictional properties which provide frictional resistance against the movement of the bit. In order to overcome this resistance energy is spent to overcome friction which results in heat being generated as a form of energy transfer between the interacting surfaces. When the heat is conducted by the bit, its material property is affected and the onset of wear takes place.

A lot of research has been done to improve the performance of continuous miners. From the experiments done on the continuous miner in cutting South African coal [13], it was observed that cutting efficiency improves markedly as the depth of cut per revolution of the drum increases, and that the best spacing of picks on the drum is twice the depth of cut. Pick shape is of secondary importance in terms of cutting efficiency, only small differences having been found between the performances of conical- and chisel-shaped tools. Later on it was found that steel are more susceptible to frictional ignition than tungsten carbide [14], and the coal cutting bits were redesigned to reduce the hazard of face ignition. Two bit designs--a mushroom-shaped bit with a conical shank and a dovetail bit with a rectangular shank were designed as well as bit wear tests were conducted in the laboratory and in an operating coal mine. In laboratory tests, for 1/8-, 1/4-, and 1/2-in-deep cuts and cutting speeds of 280, 500, and 660 ft/min, the mushroom bit had significantly longer tip wear life than the conventional bit; the dovetail bit was also superior to the conventional bit. Results of in-mine tests on the mushroom bit agree well with laboratory results. In-mine tests of the dovetail bit are underway. Experiments were also performed for frozen (non-rotating) conical bits on cutting drums for cutting action into sandstone. The number of strikes with a new bit to obtain ignition of a combustible methane-air environment was measured. Tests were made with bits tipped with both tungsten carbide and steel at several bit attack angles (angle between bit axis and sandstone surface) and initial tip angles (included angle at the tip of the new bit). Carbide-tipped bits required more strikes for ignition than steel-tipped bits, by a factor of 7 to 10. With a carbide-tipped bit, the number of strikes for ignition increased by a factor of about 3 if the bit attack angle increased by 10° or if the initial tip angle decreased by 10°. During use, abrasive wear of the frozen bit caused a flat surface to form at the tip of the bit, thereby decreasing the tip angle. As the attack angle increased, however, the new bit involved a smaller wear-flat area whereby, abrasive wear was decreased. Using the laboratory model set up, numerical models and field testing, a new bit and drum design was analyzed to evaluate their performance under different conditions. The results proved that a newer bit design and drum design were successful in limiting the amount of wear as well as improving the performance of the continuous miner and production [14].

To analyse the performance of a tool bit and fragmentation of coal due to the cutting action, an experiment was performed. Conical shape tool bit was chosen for the coal cutting purpose due to its wide application in most of the mechanical excavators. Conical bits have advantage over other bit geometry due to the lesser friction and risk of ignition of combustible methane-air environment due to protective geometry [10]. Also their shapes remained sharp due to symmetrical wear and have better efficiency due to lowest specific energy for penetration [11, 12].

II. Experimental work

The coal obtained from the workshop is of irregular shape. Initially the coal sample is prepared by cutting and trimming to fit the sample on the shaper machine. Then the dimension of the sample is measured and noted down. The sample of the coal is weighted and noted down. In order to simulate the action of continuous miner in the laboratory, shaper machine was chosen to provide the linear cutting action to the tool bit. Fig. 1 shows the schematic diagram for the experimental set up. Tool bit is attached to the tool holder by providing an extended welded part to the shank of the tool bit as shown in Fig. 2 (a). The tool is attached in the tool post of the shaper machine. The coal sample is kept and tightened on the machine. The cutting action was performed in linear forward direction at different angle and at different depth of cut. Time taken to complete one cut for a given depth of the tool bit for the coal sample is also monitored. The removed coal is collected at different depth of cuts and weighed. Each data of experiment was noted down.

The coal sample was cut to get the rectangular shape for easy fitting in the shaper machine with the following details given in Table 1. The dimension of the coal obtained after cutting was 14×14×9 cm^3 as shown in

Table 1. Details related to shaper machine and the coal sample

Weight of coal	2.28 kg
Stroke length	12.7 cm
No. of stroke per minute	24
Cutting width of rock	9 cm
Dimension of specimen	14×14×9 cm^3
Time in forward stroke	1.4 sec
Time in backward stroke	1 sec

Fig.2 (b). The cutting of coal has been done at different depth of cut and at different tilting angles.

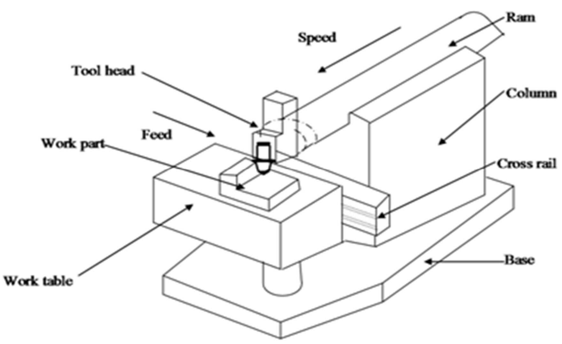
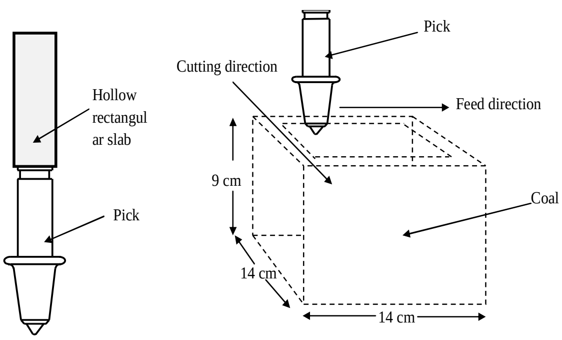


Fig. 1 Schematic diagram of the experimental set up



(a) (b)

Fig. 2 (a) Arrangement of Tool bit with holder, (b) Coal Sample and Cutting action of bit

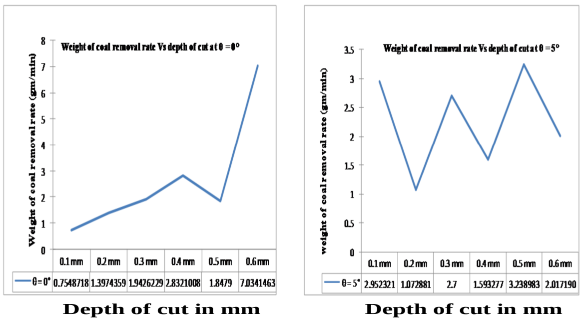
III. RESULTS AND CONCLUSION

Several graphs, Fig. 3-4, have been plotted for analysis purpose to visualize the trend between the weight loss rate and depth of cut at various tilting angles. All effort has been made during the experiment to keep coal edge intact and to simulate with the actual case.

At 0° angle of cutting, the coal sample is cut at different depth of cuts. As the depth of cut increases from 0.1 mm to 0.2 mm the weight loss rate of coal increases. Again at depth of cut 0.3 mm and 0.4 mm the weight loss rate of coal increases. At 0.5mm depth of cut the weight loss rate of coal decreases and at 0.6 mm depth of cut the weight loss rate of coal increases in great extent. Over all we observed that the weight loss rate of coal increase with the increase in the depth of cutting at cutting angle 0°. While at cutting angle 10° the trend is same as that of 0° but the maximum value of weight loss rate of coal is achieved at the early stage i.e. at lower depth of cut. Also weight removal is more which is obvious. While for 5° cutting angle the nature of increase and decrease of weight loss rate of coal is periodic. In Fig.4 (b) we can see the variation of weight loss rate of coal with the depth of cuts.

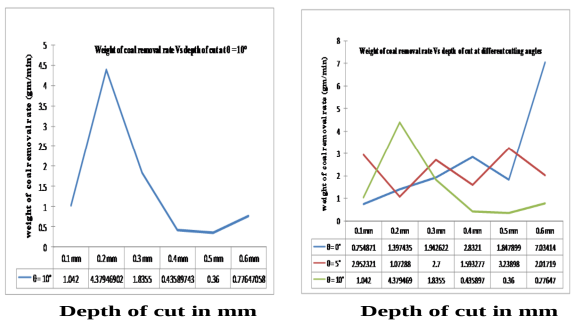
On the basis of above trend and experiments we can draw the following conclusions;

1. Fragmentation of coal is much faster near its edges and the fragmented particles are bigger as the depth of cut increases.
2. Very fine particles are produced when we kept the depth of cut very small.
3. The weight removal rate increases as the depth of cut increases. At tilting angle zero degree the weight removal rate increases as the depth of cut increases. It follows increasing decreasing and very fluctuating nature at tilting angle 5 degree.



(a) (b)

Fig. 3 Variation of weight of Coal removal rate with the depth of cut
(a) θ=0° (b) θ=5°



(a) (b)

Fig. 4 Variation of weight of Coal removal rate with the depth of cut
(a) θ=10° (b) Comparison for all three tilting angles

Further in future for the improvement of existing machines and designing new cutting tools, the aim must be to increase the service life so that the productivities of mining machines are increased by reducing stoppages for changing blunted bits. The rate of growth of the blunting area of a hit, in relation to the parameters of its cutting head, can be studied before the bit is actually fabricated and tested. Preliminary estimation of the bit wear rate enables us to assess the influence of cutting head shape and of other parameters.

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