17 International Mining Congress and Exhibition of Turkey- IMCET2001, ©2001, ISBN 975-395-417-4*

Research and Innovations for Continuous Miner's Cutting Head, for Efficient Cutting Process of Rock/Coal

A.W.Khair

Department of Mining Engineering, West Virginia University, Morgantown, U.S A.

ABSTRACT: This paper examines the fragmentation process of rock/coal by cutting head, mainly cutting tool and cutting drum. It deals with: 1) mechanics of fragmentation from quasi-static to dynamic conditions, 2) the effect of bit geometry on fragmentatiQn process and multiple bit interaction, 3) optimization of bit geometry and cutting parameters for efficiency, 4) reduction of fine products and noise generation during fragmentation process, and 5) improvement of cutting efficiency.

1 INTRODUCTION

The impact of bit-coal/rock interaction during the cutting process in underground mines is a great concern to the mining community of the world. Rock/coal cutting bears directly on rock/coal dust generation, which causes "black lung/silicosis" in miners. Furthermore, rock cutting generates radiance of sparks causing face ignitions and loss of millions of dollars m productivity, safety and economy. These face ignitions and the consequent loss of millions of dollars in productivity and compensation for respirable rock/coal dust related diseases are attributed to the cutting action of continuous miners. *

Since 1970, the U.S. Federal Government has paid over $11.7 billion to more than 470,000 miners with coal workers* pneumoconiosis and to their survivors (Newmeyer, 1981). A world report by NIOSH on work related lung disease investigations shows that a total of 13,744 deaths (see Figure 1 for further details) occurred due to silicosis related diseases during 1968-1990 (NIOSH, 1994).

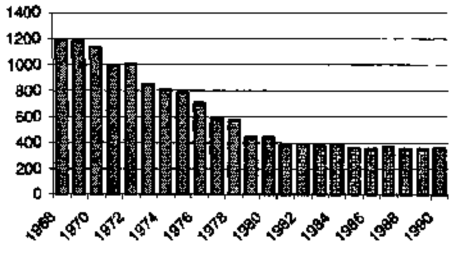


Figure 1. Number of deaths in the US due to Silicosis over 1968-1990

The high demand for coal production has increased the need for mechanized coal cutting and roof support in underground coal mines. On the other hand our coal reserve is shrinking, forcing operators to mine thin coal seams and subsequently to cut roof/floor rocks in order to mamtain sufficient clearance for equipment. At the present time approximately 65 longwall faces (Coal Age, February 1998, pp.22-27) and more than 2000 continuous miners are in operation in U.S. Enormous miles of entries are developed by these continuous miners for longwall operation as well as room and pillar mining. The amount of silica and respirable dust generated by excavating coal and cutting roofs with continuous miners is the major concern for the industry. An U.S. government printing office stressed that every year more than 250 workers in the U.S. will die from silicosis and more than 1 million U.S. workers are exposed to crystalline silica (NIOSH, 1997). Unfortunately, coal mine operations contribute significantly to these statistics.

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 repirable 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). This paper mainly deals with the major primary factors, machine operating parameters.

2 BACKGROUND

Since die introduction of continuous miners in I950's, not much change has been made in the cutting drum design for efficient excavation and reduced respirable dust generation. The problem in continuous miner head/drum is mainly associated with bit/tool and drum geometry. The bits'/tools' tips and the bodies are not designed properly, resulting in inefficient performance of machine and tools, producing high levels of noise and fine particles and generating enormous amounts of respirable dust. In a typical continuous miners drum, the bits cut face randomly and their cutting abilities mainly depend on the geometry of the bits.

In the past, enormous research has been carried out to select the design parameters for cutting tools on a trial and error basis (Organiscak, et al, I995). There are two shapes of cutting bits commonly utilized, namely, wedge type and point attack type. Although point attack type bits are used most frequently in the US, research indicates point attack bits suffer a lot of bit tip wear and damage. This is largely due to their inefficient rubbing contact with the wall of the cut groove (ridges/lands) (Reddy, 1998).

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. A study was carried out to study the principles of bit wear and dust generation (Khair, et al, 1992). In this study four types of point attack/conical used bits were obtained from different underground coal mines. The analysis showed that many bits did not rotate properly during cutting. The intention of using conical bits in the United States coal mining was to keep bit tip sharp, it should wear symmetrically, as it rotates during the cutting process. As rock and coal debris plunge into the spacing between the bit blocks and bits, lock in of the bit into the bit block results, The same study showed that worn bits with 15% weight loss generated about 26% more dust man the new bits. Researchers at USBM (Roepke, et al, 1976) indicated that the rate and form of bit wear highly depend on bit temperature. Diffusive wear becomes the dominant form when bit temperature is higher man the critical temperature. Bit velocity is the main parameter to influence the bit temperature. The wear rate of steel, stellate and carbide tools is reported to be independent of bit velocity when the bit velocity is below a critical value of 165 to 220 ft/min. Wear was observed to increase very rapidly above the critical velocities (Roepke, et al, 1976). Since bit velocity increases the temperature of the bit, it is necessary to insure that bit velocity is below the critical value. However, low bit velocity will reduce production.

The major problems in the cutting action of the rotary cutting drum, which excavates the cutting face, are the following: (1) non-uniformity of the cutting depth for each individual bit along the cutting path, (2) generating secondary dust, which may be much more than the primary dust generation due to cutting action, (3) excavating material in a confined state/solid face without pre-cut free faces/slots. In a rotary cutting action the shape of the groove along the path of an individual bit resembles a crescent moon. Each bit on the drum starts the cutting face from zero depth of cut and as the bit penetrates further into the face, the depth of cut increases to a maximum at the center line of the path of each cutting bit, then the depth of cut decreases to zero when the bit exits the cutting face. Researchers in USBM developed a linear cutting drum (Roepke, et al, 1995). A comparison of laboratory experiment utilizing drums of the same size indicated that, when both drums have reached 75% of the maximum cut depth, the rotary drum has removed approximately 33% of the total volume, while the linear drum has taken only 15% in the shallow cutting region (Roepke, et al, 1995). However, under variable seam thickness, which requires both sumping and shearing, me difference in total dust generation may not be as significant, comparing rotary cutting and linear cutting of this particular design. One of the important aspects of this design is to modify the regrinding process of the typical rotary cutting drum. The linear cutting drum did not get out of the laboratory because of two major reasons: a) the concept was totally unfamiliar to the mining industry; b) the drum required a very high torque gear box to be practically utilized.

A laboratory study was carried out at WVU to study dust generation due to regrinding (Khair, et al, 1991). The assessments of dust generation, in this study, indicated that dust generation by regrinding depends on the size of the particles being cut during primary excavation (i.e., cut by the first line of bits). Higher dust concentration coefficients were obtained by regrinding finer particles. Increasing depth of cut creates less fine particles and reduces dust generation by regrinding. Among the parameters considered in this study the depth of sump has the most significant effect on dust generation by regrinding. Dust generation also significantly depends on hard grove grindability index. The coal with higher grindability index has higher dust concentration coefficients. Higher velocity of cutting head causes higher dust concentration. Dust concentration by regrinding is linearly proportional to the amount of coal left for regrinding (Khair, et al, 1991). This study recommends that loading the entire coal removed/excavated in each cutting cycle will help to reduce regrinding. It has been said that "using blunt, high speed bits, {continuous mining machines) probably are the best machines for forming dust that could be invented, except for a grinding stone" (Roepke, et al, 1995). This concern has been substantiated. In a study by USBM (Roepke, et al, 1995) indicated that a continuous miner produces 70% of total dust while sumping, and only 20% while shearing. The remaining 10% is attributed to gathering and loading.

3 RESEARCH ON ROCK/COAL CUTTING

Efficient rock/coal cutting is a result of the optimum use of available resources in a continuous mining system. Research has demonstrated that specific energy and specific respirable dust must be kept at minimum to produce the optimum parameters of the rock/coal breakage process.

Mechanisms of Rock/Coal Fragmentation;

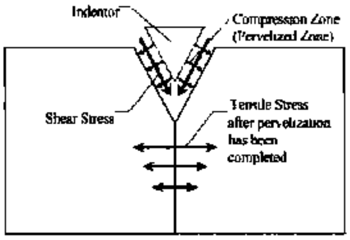


Figure 2 Shows stress develop during indentation

The fracturing process is governed by quasi-static and dynamic forces. In a recent study by Khair, et al. (2000a) (2000b) the fracturing process in Tennessee sandstone specimen, subjected to a wedge indentor is exhibited holographically. From the failure process point of view, it's obvious that initial wedge-rock interaction results in high stress concentration (compressive and shear, Figure 2) at the area of the contact zone, causing micro-failure of material in the vicinity of the contact zone (between wedge and rock, Figure 3). As the stress exceeds the strength of the material, it results in pulverization of the interface zone and stress redistribution in the specimen (see Figure 4). As the loading continues, the wedge penetrates further and pulverizes the contact zone (see Figures 5-6). The process continues and is reflected in Figure 7 until the extension of the pulverization zone stops where sufficient tensile stress (splitting stress) develops to initiate failure, (see Figures 8-9), Figure 10 shows the results of different experiments, using special holography. Displacements at the beginning of loading process are very high and diminish as the specimen reaches failure. This reduction of displacements results in pulverization of the interface and stress distribution occurs at the area of contacts between wedges and rocks At that instance tensile stress sufficiently develops and indicates that lateral displacement perpendicular to the direction of wedge face develops very high prior to the specimen failure for three wedge angles. Failure of the specimen occurs (see Figure 10). The thickness of the pulverization zone in the wedge-rock interface mainly depends on two factors. (!) material characteristics such as brittle, ductile behavior of material in particular cracks, discontinuities, porosity and flaws existing in the material, which are more susceptible to become pulverized and allow wedge to penetrate deeper into the material. To extrapolate this fact further, ductile/soft material requires deeper wedge penetration prior to splitting/fragmentation than brittle/harder material; (2) wedge angle, the higher the wedge angle less wedge penetration and less crashed material produced. However, higher wedge angle subjects more wear (see Figure I la-b)

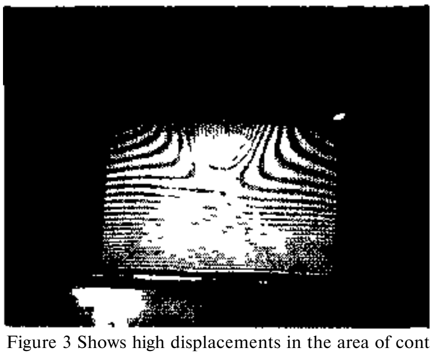


Figure 3 Shows high displacements in the area of contact wedge-rock due to high stress concentration, perpendicular to the specimen face.

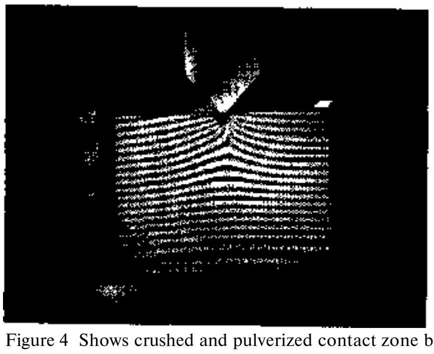


Figure 4 Shows crushed and pulverized contact zone between wedge-rock

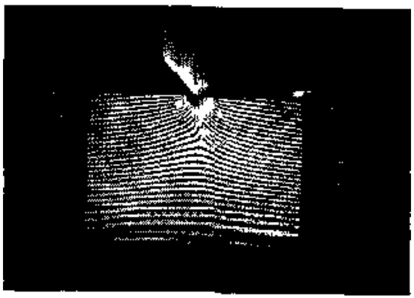


Figure 5 Extension of pulverize zone in the area of contact zone between wedge and rock

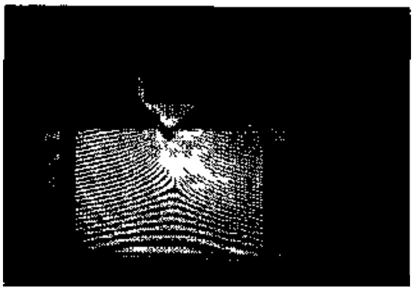


Figure 6 Shows continuous process of wedge penetration and displacements/pulverization development in the rock

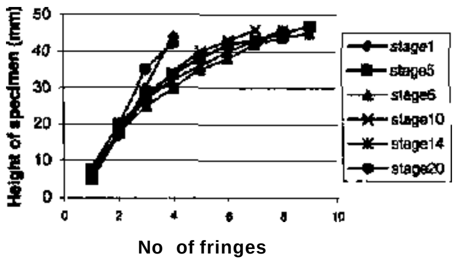


Figure 7 Displacements using 90° indentor in unconfined condition, indicates variation of displacement curve due to stress redistribution

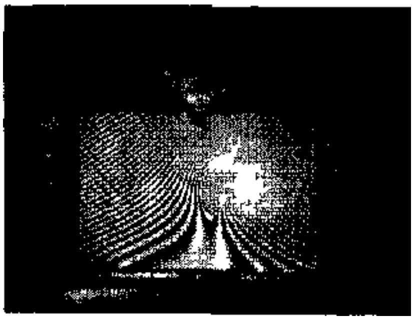


Figure 8 Shows end of pulverization on the line of loading action and development of tensile stresses

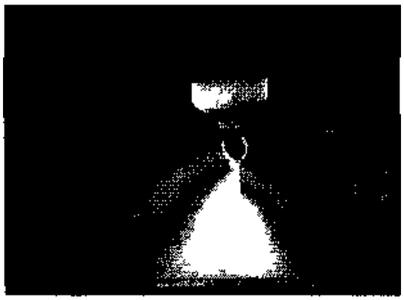


Figure 9 Shows pulverize zone and fracture extension in the specimen

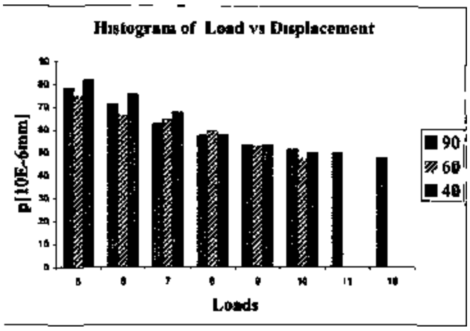
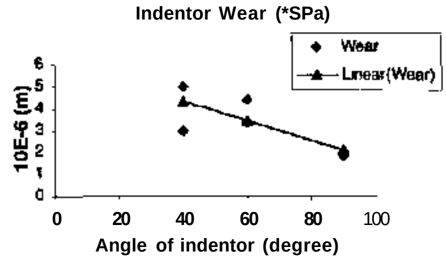
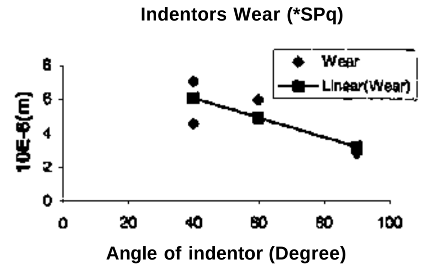


Figure 10 Histogram of Load and Displacements for three indentor angles in lateral direction



'Unfiltered arithmetic mean of the departures of the surface from the mean value of the fractured surface

Figure 11 a Correlation between angle of indentor and bit wear



Unfiltered RMS parameter corresponding to Spa

Figure 11 b Correlation between angle of indentor and SPq for indentors

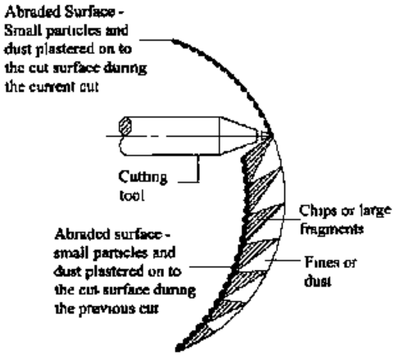


Figure 12 Simplified diagram of crushing and chip formation when cutting coal with continuous miner

Fracture process in coal/rock by rotary cutting showed that the dynamic forces causes fracture formation and fracture extension, while the quasi-static forces are responsible for grading the fracture surface. Observations during the tests indicated that after the cutting head induces certain fracture (different intensities, magnitudes, and lengths), its rotational velocity slows down. Analyzing the cutting action, when the bit enters the coal it indents and compresses the coal under it and shears off the fragments. This process yields coal fragments, coarse and fine, and dusts particles (see Figure 11V The key to analyzing and understanding the source of dust generation is to identify the different phases of the cutting process and to correlate them with the particles. Previous investigators have observed that during the indentation of a cutting bit into a brittle material, two phases occur (Paul, et al. 1965) (Miller, et al. 1968). These are called the crushing phase and chipping phase. This was later extended to linear cutting by observing the cutting action under very low speed (Warner, 1970). In this study it was theorized that when the bit first contact inelastic subsurface cracking takes place. Such an action leads to crushing due to the coalescence of the cracks. Crushing and subsurface cracking will produce fine fragments and dust. It was observed that the cutting and thrust forces build up and increase during the crushing/pulverizing phase of the material and drop when a major crack is generated, resulting in chip formation.

Cutting Parameters:

The important parameters of rock/coal cutting are 1) attack angles, 2) bit geometry, 3) depdi of cut, 4) bit spacing, 5) water-jet assisted pressure.

I) Bit Attack Angle:

Research has been carried out by Khair, et al (1989) utilizing four different attack angles, 15°, 30°, 45°, and 60°, were used in this study (Fig. 12). The most ideal condition for force transmission by the bit to the coal will be a 30°-45° attack angle, where the area of contact between the bit and coal is at a minimum and causes a high stress concentration in the coal block. As a result, less force is required to break the coal. The smaller attack angle will not only require a larger normal force (thrust) to penetrate the coal, consequently resulting in more friction heat, especially during the quasi-static loading condition (grading). The 60° attack angle is similar to the 15°; however, in this case the front portion of the bit will have a larger surface area of contact with the coal. Its influence on fragmentation will be during the dynamic loading cycle and the larger area of contact will make the bits behave as if they were blunt.

Figure 13. Shows attack angle in the experiment

2) Bit Geometry:

Conical bits are commonly used in the U.S. mining industry and discussions are focused on this type of bit. In regards to bit geometry, there are two elements associated with bit geometry, 1) bit tip and 2) bit body. Research has been carried out by many investigators to characterize bit geometry i.e. bit tip angle, and size, bit body geometry and stream linear of bit tip and body for efficient fragmentation, durability, ignition, respirable dust generation, specific energy consumption, noise generation, breakout angle and multi bit interaction (Roepke, et al. 1976, Khair, et al. 2000a, Khair, et al. 2000b, Roepke, et al. 1983, Khair, et al. 1989, Srikanth, 2000, Khair, 1996, Khair, 2001).

3) Depth of Cut:

Past research indicated that as the depth of cut increases the specific respirable dust is reduced. Deeper cutting enable interaction between adjacent cuts and help produce larger chips of material. Roepke and Hanson (1983) found that the average cutting force increases with increase in depth of cut while the specific respirable dust and specific energy decreases with depth of cut.

It is known that a proper depth of cut to bit spacing ratio reduces specific dust generation. This ratio depends on machine cutting parameters and physical and mechanical properties of rock (Achanti, 1998). Research work was conducted by a number of people on rotary cutting bits. Research at USBM (Roepke, et ai. 1976) demonstrated that the specific energy and airborne dust (ARD) decrease significantly as the cutting depth increases and the optimum tool spacing to cutting depth ratio ranges from 2 to 3. Further study by the USBM researchers (Roepke, et al. 1983) concluded that different bits do not affect the ARD as significantly as cutting depth or specific energy, but various bits have different forces and energy requirements necessary to maintain a prescribed cutting depth.

Barker (1964) and Pomeroy and Brown (1968) reported that optimum spacing depends on the depth of cut. For a cut spacing at which neighboring grooves interact, the cutting forces decrease after reaching a maximum. The maximum normally corresponds to the condition of high product volume, low specific energy and low dust generation. Research also indicated that specific energy decreases with depth and spacing (Srikanth 2000, Khair, 2000).

Many studies have addressed the influences on respirable dust generation during coal cutting process. Research was conducted at WVU (Reddy, 1998) utilizing a series of single and multiple bit experiments on coal using a laboratory scale cutting machine in order to investigate the sources of respirable dust generation both at macro and micro levels, Khair, et al (1989) documented several issues in rock cutting process that need to be addressed and the concern for respirable dust in the report submitted to USBM. The Bureau of Mines conducted a series of experiments using four different coal types to determine the effect of attack angle and asymmetric bit wear on airborne respirable dust (ARD) generated by point attack bits and in energy consumption (Roepke, et al. 1983). They established that the depth of cut had significant effect on the respirable dust and specific energy

Research conducted at WVU indicates that specific respirable dust increased with increasing bit spacing in rotary cutting. As the bit spacing increases the grooves made by the bits do not interact and hence the ridges do not break. Instead of the formation of major chips, regrinding occurs in die grooves producing significant amount of fine dust. As the cutting depth increases the amount of respirable dust generated reduced as deeper cuts enable me interaction of adjacent cuts and help in production of major chips (Achanti, 1998). A series of preliminary laboratory experiments were carried out at the Department of Mining Engineering at WVU (Khair, et al. 1989). Figure 14, shows experimental set up. Figure 15, shows test coal block, Figure 16a-c shows tested coal blocks in different cleat directions and bit spacing. In this study a series of experiments were run with a 7.62cm (3in) spacing. Three bits were mounted in an echelon pattern and a 6.35-7.62cm (2.5-3 in) deep cut was made without breaking the boundary walls/ledges between the bit paths (see Figure 16a). This series of tests were carried out for the 15°, 30°, 45°, and 60' attack angles. With 3.80cm (1.5in) spacing and five bits mounted m an echelon pattern, the side walls/ridges of the bit path were broken when the coal blocks were tested In both face and but cleat direction (see Figures 16b and 16c). In these experiments the fracture surface was more regular when tested against butt cleat, walls/ridges between the cutting paths broke only partially and irregularly (see figure 16c). A total breakage of the walls/ridges created a free face (see figure \6b), thus reducing the required resultant forces to cut the coal (Khair, et al. 1989). The concept of relationship between depth of cut and bit spacing in order to remove lands/ridges between the cutting paths is illustrated by Figure 17. As it was indicated earlier that depth of cut not only reduces primary and secondary dust generation, but also reduces required specific energy, depending on bit geometry. A series of preliminary experiments were carried out by Khair (1996) Figure 18 shows typical experimental setup and Figure 19 shows tested rocks utilizing bits of different geometry. Among the tested bits, US2 performed very well. This high performance of the US2 type bit was due to two geometric parameters, namely high clearance angle and prism shape of the cutting face of the bit. which further reduced the surface contact area of the bit during the cutting process. These two factors reduced the specific energy consumption for the bit, in particular, under deeper cutting condition (i.e., at 3mm depth of cut, specific energy consumed by the bit is 18.4 MJ/m^3, and at an 18mm depth of cut, the consumed specific energy was reduced to 24 I MJ/m^3 with a corresponding mean nominal force to mean cutting force ratio of 0.91 and 0.53, respectively). Results also indicate that specific energy consumed by the bit decreases with depth of cut. The damaged surfaces of the rock corresponding to different depth of cut are present in Figures 20 and 21. In deeper cutting most of the energy was consumed in the fragmentation process rather than grinding material, hence resulting in a larger product size and fewer fine particles (see Figure 22-24)

Figure 14 Experimental setup earned out in 1989.

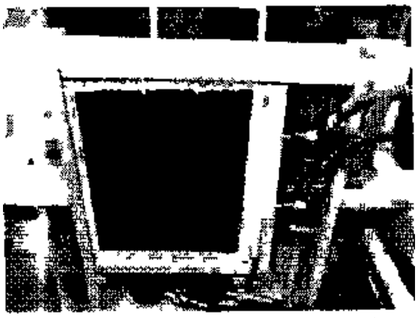


Figure 15 Typical Specimen located in the confining chamber and ready for experiment

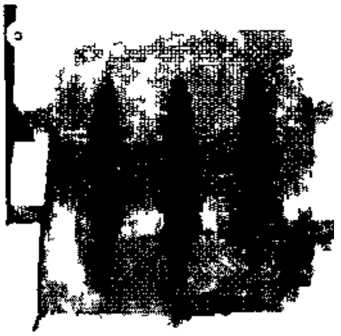


Figure 16a Coal blocks cut with 3 in bit spacing ta^e cleat

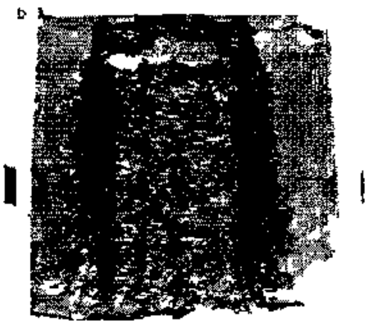


Figure 16b Coal blocks cut with 1 5 in bit spacing face cleat

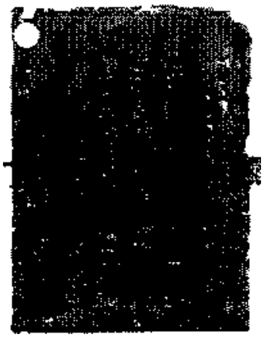


Figure 16c Coal blocks cut with I 5 in bit spacing but cleat

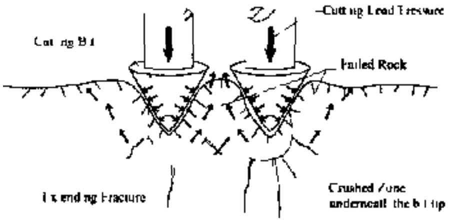


Figure 17 Relationship between depth of cut and bit spacing

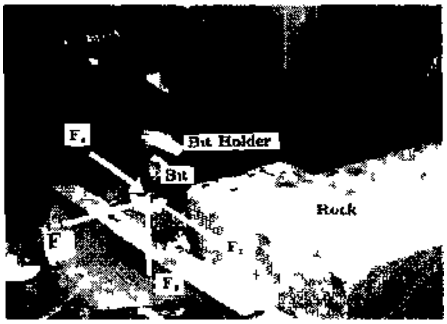
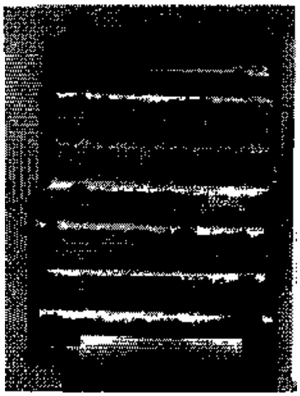


Figure 18 Typical experimental setup



I Photograph of the cut surface tested Godula sandstone block

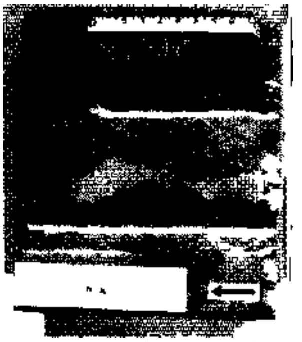
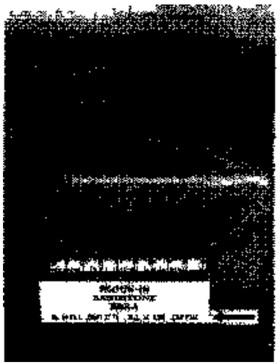


Figure 20 Cut surface of the rock at 12 and 9 mm depth of cut utilizing US2 bit



"Figure 21 Cut surface of the rock at 18mm depth of cut, utilizing US2 bit

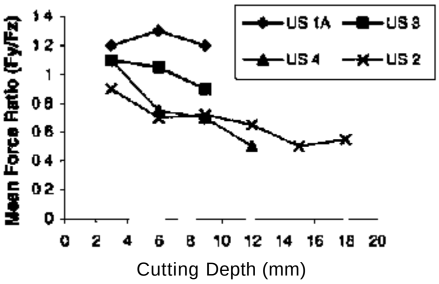


Figure 22 Variation of mean normal force/mean cutting force with increasing depth of cut

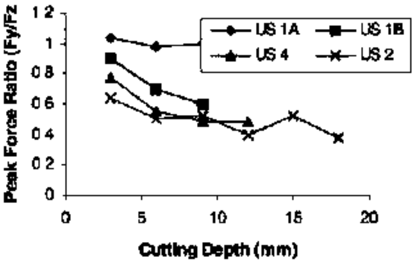


Figure 23 Variation of mean peak norma! force/mean peak cutting force with increasing depth of cut

4) Bit Spacing

Linear cutting has been earned out in order to study the influence of bit spacing on the energy consumption and amount of noise produced during cutting (Khair, 2001) The results indicate that the noise levels usually mcrease with an increase in the cut spacing to depth of cut ratio for individual bits There is an increase in the noise level and energy consumption of 4 5% and 24 1% respectively when the bit spacing to cut depth ratio was increased from 1 to 2 Optimum bit spacing reduces confinement and provides free space, which results m less energy consumption and reduces dust generation Furthermore the linear cutting indicated that the noise levels mcrease as the bit tip size increases The noise levels increased by about 5 dB with a larger body and tip size Therefore by an optimum bit spacing to depth of cut ratio and optimum bit tip size a reduction up to 10 dB noise resulted during the cutting process It should be emphasized that the bit tip size is not the only parameter that effects bit performance, but also the geometry of bit tip and bit body, a stream-lined shape is important Figure 25 shows the types of bits used Figure 26 shows the linear cutting experimental setup, and Figure 27 shows the cutting process (Khair, 2001) Experiments conducted at WVU, utilizing rotary cutting machine, indicates energy consumption and specific respirable dust reduces as the bit spacing to depth of cut ratio decreases from 2 to 0 3 (Snkanth, 2000) m another expenment the amount of respirable dust produced increases as the bit tip angle increases from 60° to 75° and it reduces from 75° to 90" (Achanti, 1998)

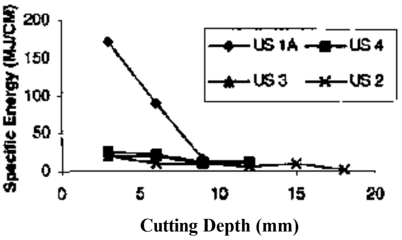


Figure 24 Variation of specific energy with depth of cut

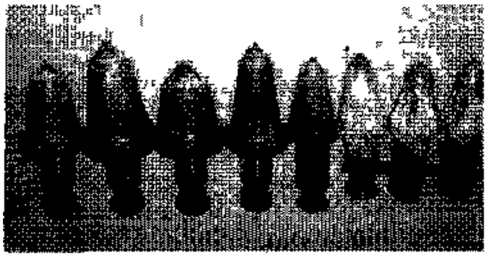


Figure 25 Shows the types of bits used in experiments

Figure 26 Shows the linear cutting experimental selup

Figure 27 Shows the cutting process

5) Water Jet Assist Cutting:

The external water spray system is the typical technology associated with continuous miners in underground coal/rock cutting process. In this technique a canteen of water is sprayed above the cutting head in order to suppress the respirable dust. However, the internal water spray jet system involves a water-jet directed towards the rock bit interaction point. This is known as "wet drum" and is similar to a shear drum. This results in keeping the bit cool, suppressing dust, reducing cutability index of the rock and increasing deep cutting performance ofthe cutting drum which results in reduced specific dust generation in underground and inhibit sparks to retard ignition. Studies carried out at WVU (Khair, et al. 1998a, Khair, et al. 1998b) in regards to cutting rock under three experimental set-ups, a) dry cut, b) external water spray cut (see Figure 28), and c) internal water spray jet cut (see Figure 29). The results were astonishing in terms of bit wear, machine penetration/cutting force, depth of cut and respirable dust generation. A high content of quartz with quartz cement found in Tennessee sandstone caused excessive removal of material from the bit body, in dry and external water spay cutting, and damaged tip of bit, while no substantial damage was observed when water spay/jet method (see Figure 30a, 30b, and 30c). Figure 30a shows wear of the bits with respect to the new one and Figure 30b and 30c show the variation of cumulative weight and height loss of the bits respectively in the above experiments. Even though, the dust was not measured in a wet set-up since the wear on the bit is due to the abrasion and impact of die bit on rock, therefore, their action was minimum, water spray/jet method application and it certainly has changed the mechanical property of rock in comparison to the dry and external spray system. The results of these studies (Khair, et al. 1998a, Khair, et al.!998b) showed that wear rate on the cutting bit is a controllable factor, and the potential for other problems such as fractional ignition and respirable dust could be reduced. In a communication with a JOY Mining Machinery Engineer it was indicated that their wet drum continuous miner in a Utah mine, reduces respirable dust up to 80%, dust samples reduced from 2.0 mg/cu.m to 0.4 mg/cu.m with water flow rate of 26.5 g/m.

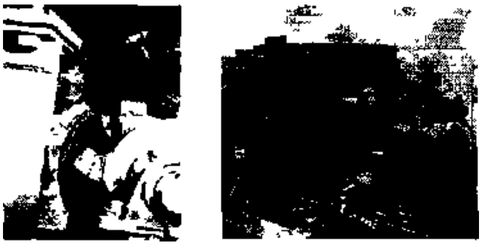


Figure 28 and Figure 29 Shows external water spray cut and internal water spray jet cut respectively

Figure 30a. Shows wear of the bits with respect lo the new one.

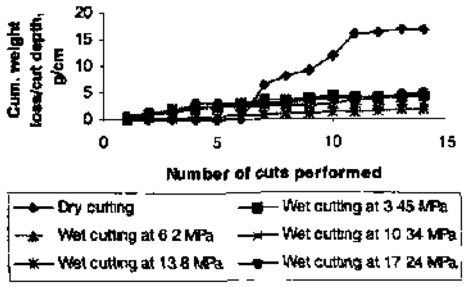


Figure 30b. Cumulative weight losses in a series of 14 cuts performed on Tennessee sandstone

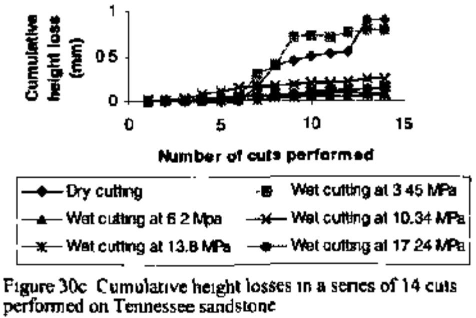


Figure 30c Cumulative height losses in a series of 14 cuts performed on Tennessee sandstone

4 IMPROVEMENT

In the past, technological innovation in mine equipment and machinery, resulting from research, had little chance of implementation in field application. However, this trend has changed in the last few years, because of safety concerns and high productivity demands. Continuous miners of today are more highly advanced in hydraulic, electrical, electronic, and mechanical technology than the ones built a decade ago. Unfortunately the cutting head of continuous miners have received the least attention to improve coal/rock fragmentation, reduce dust and increase efficiency of the machine. However, some important research in the area of cutting drum has been carried out which will enhance the performance of the cutting drum. There are many types of cutting tools with different bit geometry shape, size, and tool tip available to cut materials of different strength and abrasivity. Polycrystalline diamond compact (PDC) bits could be used for hard and abrasive materials, however, the use of such a bit in the field is restricted by cost. Unfortunately, the geometries of these cutting tools are not optimized to reduce respirable dust and specific energy. The important elements for cutting tools are deep penetration with least wear and energy consumption. In a research work by Khair (1996), recommendations in regards to optimum bit geometry were presented. Following these recommendations, a series of new cutting tools were developed by two major tool-manufacturing companies. Research on optimization of cutting tool, for cutting different geological materials, is underway by the author.

During sumping process, where most of the regrinding takes place, scrolls, similar to the longwall shearer machine, will help to transport material from the sump to the gathering arms. The scrolls on the cutting head of some continuous miners, used for trona mine are implemented and the results are highly favorable. The productivity of the continuous miner has increased significantly by increasing depth of cut. However, if the depth of cut to bit spacing is not optimized it results in excessive amount of respirable dust generation and high energy consumption. If the ridges between the bits were not broken/fragmented during bit penetration there is crashing of these lands/ridges by the bit blocks. The use of water jet assisted cutting has been implemented in a number of continuous miners in relatively dusty coal mines. Of course water jet assisted mining not only suppresses dust generation, it also helps retard ignition, facilitates rotation of bit in bit block, and increases efficiency of the cutting tool and cutting head. Perhaps the most inefficient cutting of continuous miner drum is lack of free face. The geometry of the drum is not modified to cut material toward free the face. Research in this area is underway by the author.

5 CONCLUSIONS

Efficient utilization of continuous miner cutting head requires optimization of cutting tool, and drum geometry, understanding of fracture mechanisms associated with cutting material and constructing cutting tools ideal for the type of material to be cut. It is essential to design tools for reduction of dust generation and cutting efficiency. Implementation of scrolls, internal water spray system, with deep cutting and optimum depth of cut to bit spacing, certainly increase productivity, efficiency, reduce respirable dust generation, retards ignition and increase the useful life of the cutting tools.

REFERENCES

Achanti.V.B., 1998, Parametric Studyof Dust Generation with Ridge Breakage Analysis Using a Simulated Continuous Miner, Ph.D. dissertation, Department of Mining Engineering, WVU, Morgantown, WV. pp.83.

Barker, J. S., 1964, "A laboratory Investigation of Rock Cutting Using Large Picks," International Journal of Rock Mechanics and Mining Sciences, Vol. I, pp.519-534.

Coal Age, U.S. Longwall Census, February 1998, pp. 22-27.

Khair. A. W., "The effect of bit geometry and size on cutting parameters in linear cutting. 2001, SME-AIME Annual Meeting and Exhibition, Denver, CO, February 26-28, 2001, preprint Number 01 -86, 12pp.

Khair, A. W., "The effects of bit geometry on rock cutting efficiency". Applied Occupational and Environmental Hygiene, Vol. 11, Number 7. July 1996, pp. 695-700.

Khair, A. W., "The effects of cutting tool design on respirable dust generation", Proceedings of International Scientific and Technical Conference on Respirable Dust Hazard Control in the World Mining Industry, Szczyrk, Poland, Sept.17-19,1996, pp. 79-87.

Khair, A. W., and Achanti, V. B., "Laboratory Investigation of Bit Wear in Water Jet Assisted Cutting of a Continuous Miner", Proceedings of 3rd North American Rock Mechanics Symposium (NARM '98), Cancun, Mexico, Jan 3-5,1998b.

Khair. A. W., and Achanti, V. B., "Experimental Investigation of Rock Fragmentation Efficiency of a Simulated Wet-Drum Continuous Miner", Proceedings of Pacific Rim International Conference on Water Jet Technology, New Delhi, India, Feb. 3-5. 1998a, pp. 460-*66.

Khair, A. W., Addala, S., and Pezowicz, C, "Effect of Cutting Tool Angle on Failure Mechanism of Rock in Rock-Tool Interaction", Proceedings of the Ninth International Symposium on Mine Planning and Equipment Selection, Athens, Greece, November 6-9,2000b, pp. 601 -606.

Khair, A. W., Addala, S., Pezowicz, C, and Bernakiewicz, M., "Fracture Process in Rock by Wedge Indentors utilizing Holographic Interferometry, Process of the Fourth North American Rock Mechanics symposium NARMS 2000, Seattle, W A, USA, July 31-August 3.2000a, 6pp.

Khair, A. W.. Reddy, N. P., and Quinn, M. K., "Mechanisms of Coal Fragmentation by a Continuous Miner", Journal of Mining Science and Technology, March 1989, pp. 189-214.

Newmeyer, G.E., "Cost of black lung program". Mİn. Congress Journal, 67(11) 1981, pp. 74-75.

Khair, A. W., Xu, D., and Ahmad, M., "Principles of Bit Wear and Dust Generation", Proceedings of New Technology in Mine Health and Safety. SME, Littleton, CO, February 1992, pp.175-183.

Rhair, A. W., Xu. D., "Laboratory approach to study dust generation due to regrinding", Proceedings of 5th U.S. Mine Ventilation Symposium, SME Publisher, Littleton, CO. 1991, West Virginia University, Morgantown, WV, June 3-S, 1991,pp.215-224.

Miller, M. H., and sikarskie, D. C, "On the penetration of rock by three-dimensional indentors", Int. J. Rock Mech. Mİn. Sei., 1968, Vol 5, pp.375-398.

Organiscak, J.A., Khair, A. W., and Ahmad, M., Studies of Bit Wear and Respirable Dust Generation, SME-AIME Annual meeting and exhibit, Denver, CO, March 6-9. 1995, Preprini No. 95-214. Also in SME Mining Transactions/Annual Bound, Vol. 298, 1995, pp. 1874-1879.

Pomery, C. D., and Brown. J- H., 1968, "Laboratory Investigation of Cutting Process Applied to Coal Winning Machines", Journal of Strain Analysis, Vol. 3, No. 3, pp. 232-243.

Paul, B., and Sikarskie, D. L„ "A preliminary theory on static penetration by a ridge wedge into brittle rock material", Transaction of SME-AIME, Dec. 1965, pp.372-383.

Reddy, N. P., 1988, "Characterization of Coal Breakage by Continuous Miners", Ph.D. dissertation, Department of Mining Engineering, WVU, Morgantown, WV, 184pp.

Roepke, W. W., et a!., (1995), Improved Performance of Linear Coal Cutting Compared with Rotary Cutting, USBM, Rl 9536, pp.34. .

Roepke, W. W., and Hanson, B. D., (1983). "Effect of Asymmetric Wear of Point Attack Bits on Coal Cutting Parameters and Primary Dust Generation", USBM, RI 8761, 16pp.

Roepke. W. W., Lindroth, D. P., and Myren, T. A., (1976), "Reduction of dust and Energy During Coal Cutting Using Point Attack Bits With Rotary Drum tested and produced the same or less, -.32cm (-1/8 in) product.

Srikanth Addala, 2000, Relationship between Cutting Parameters and Bit Geometry in Rotary Cutting, Master Thesis in Progress, Department of Mining Engineering, WVU, Morgantown, WV.

U.S. Department of Health and Human Services, Division of Respiratory Disease Studies, National Institute of Occupational Safety and Health, Work related lung disease surveillance report. August 1994.

U.S. Department of Labor, National Institute of Occupational Safety and Health, A Guide to working safety with Silica, 1997, pp.551-664.

Warner, E. M., 1970. Machine and cutting element design, Mine Conference J. August, pp35-43.