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CHARACTERIZING RESPIRABLE DUST GENERATED FROM CUTTING POTASH IN LABORATORY FULL SCALE CUTTING TESTS WITH RADIAL PICKS AT DIFFERENT STAGES OF WEAR

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ABSTRACT

Respirable rock dust poses serious long-term health effects to workers in mining and tunneling underground hard rock environments. When inhaled, respirable silica particles commonly found in quartz and other minerals will scar sensitive lung tissue and cause irreversible lung diseases. Characteristics such as concentration, type of mineral, particle size, and particle shape inhaled can harm workers to various extents. Therefore, this study characterizes rock dust particles less than 100µm in aerodynamic diameter that are released from cutting hard rock in the underground mining environment. In this study, laboratory full scale cutting tests on samples of potash rock were performed with radial picks to generate dust. Three stages of pick wear were tested: new, moderately worn, and severely worn. Comparisons between different stages of pick wear to dust concentration, size distribution, and particle shape characteristics are drawn from this study to start determining the scenarios when the released airborne dusts become potentially most hazardous for workers. Although further testing needs to be conducted to make viable conclusions, the moderately worn pick, or the pick with the most blunt tip, in these experiments are potentially the most dangerous. The blunt pick tip released the highest concentration of dust and generated particle shapes with the highest aspect ratio compared to the other two picks. The preliminary results of this study allow for the further development of optimum bit management and maintenance systems to control the exposure of respirable dust to mine workers.

INTRODUCTION

Respirable dust exposures to workers is an issue in the mining and tunneling industry because breathing in particles less than 10µm in aerodynamic diameter can cause irreversible lung diseases such as coal-workers pneumoconiosis [1][2], silicosis [3][4], and other life-threatening lung diseases [5]. Since the 1970s, US Mine Safety and Health Administration (MSHA) has implemented regulations to limit worker's exposures to respirable dusts [6]. The mandated exposure limits showed great progress in increasing industrial hygiene standards as the cases of lung diseases dropped drastically for the following twenty years [7]. However, in the 2000s, cases in lung diseases in underground mine workers started to increase again, especially in coal mines in the Appalachian region [8][9][10][11].

MSHA implemented regulations in 2014 such as *Lowering Miners' Exposure to Respirable Coal Mine Dust Including Personal Dust Monitors* to update the previous dust laws to be more applicable to the modern work place. The new rule, effective 2016, changed the permissible respirable dust concentration limit from 2 to 1.5 mg/m^3 and also requires mine operators to wear direct-reading, personal dust monitors [12]. MSHA's new regulations are effective in protecting workers from exposures to high concentrations of dusts and this method will continue to protect workers underground. However, it is still uncertain what is the underlying cause for the increase in lung related health problems in terms of increased cases of lung diseases and deaths.

Researchers are investigating other possible causes for worker's lung diseases beyond effects of concentration. There are studies on the shape of particles, the size distribution of particles, nanoparticle influence, mineralogy affects, changes in drilling into roof strata or varying seams, and location of mine [13][14][15][16][17][18]. Although these comprehensive studies have increased understanding on characteristics of dust particles, it is still uncertain what is harming workers.

The standard mode of production in many of the soft to medium rock formations is the use of mechanical excavation units such as continuous miners, roadheaders, and drum shearers which use various types of pick cutters. There are limited studies on how pick tip geometry and wear influences dust generation. The limited previous investigations on pick tip shape influencing dust generation only include analysis on the concentration of dust [19][20][21][22]. Alongside concentration, this study characterizes dust in terms of dust mineralogy, particle shape, and size distribution for radial bit tips at a new, moderately worn, and severely worn levels of wear. Additionally, scanning electron microscopy, laser diffraction analysis, and modern image analysis programs are used to characterize respirable particles beyond what is reported in previous studies.

The goal of the research presented in this paper is to provide characteristics of dust particles generated from different stages of pick wear to eventually aid mine operators in making decisions on bit management relative to dust exposure controls. Various dust characteristics determine the health impact on workers and are investigated separately for the purpose of this study. Therefore, a concrete recommendation cannot be made from these preliminary experiments about when to increase dust controls in relation to bit wear because there are complex interactions between all the dust characteristics. Instead, each characteristic is presented individually. It is the vision of this experiment to provide a preliminary study of dust characteristics for further experiments such that eventually concrete recommendations can be provided to mine operators on when to increase dust suppression systems. In the end, by eventually providing dust control recommendations at specific and strategic stages of bit wear, it is possible that there will be a reduction in the number of mine workers contracting harmful lung diseases.

RESEARCH METHODS

Sample Preparation and full scale cutting tests

When studying the rock excavation process, it is critical to perform the test in full scale. This means that the full-size cutting tool (as seen in Figure 4) is used in cutting the target material with the spacing and depth of penetration used in the field. Full scale tests also facilitate more accurate particle size distribution analysis, including the study of fines generated while cutting. These fines constitute the majority of the respirable dust that can stay in the air and be inhaled by workers in downstream operations, while it may cause other inherent problems in operations, including the mineral processing stage.

To conduct a full scale cutting test, large samples of rock procured from the mine site are cast into a steel box with appropriate concrete to secure the sample in place. For this study, large potash samples received from an underground mine in Canada were cast for cutting tests. Each sample was then installed into the linear cutting machine (LCM) at the Earth Mechanics Institute (EMI) at the Colorado School of Mines (CSM) for full scale cutting tests. As shown in Figure 1, the potash block cut into three samples is considered fairly homogenous for these experiments. They are considered close to homogenous because throughout cutting each block from top to bottom, the distribution of crystals was fairly uniform and there were no intrusions or rock joint sets throughout the samples.

Figure 1. Looking down on each of the three potash blocks used for full scale cutting. Block 1 was used for the new pick, Block 2 was used for the moderately worn pick, and Block 3 was used for the severely worn pick. The length and width of each block was about 1 meter by 0.9 meter (3.5 feet by 3 feet) respectively. Picks used to cut rock are in Figure 4.

The LCM, as seen in Figure 2, is used to simulate full scale cutting tests on rock. The LCM moves the rock block underneath the bit in a linear manner, forcing the bit to dig into the samples while the normal, drag, and lateral cutting forces are measured and recorded by a high capacity 3D load cell. With this, for each test, a specific set of parameters are implemented. The parameters include the spacing between lines of cuts along the surface of the rock, the depth of pick penetration into the rock, and speed of cut. All potash blocks were tested with a 12 cm (4.75 inch) spacing between cut lines, a 2.67 cm (1.05 inch) penetration depth per line, and 250 mm/sec (10 inch/sec) cut speed. All experiments contained the same number of cut lines to ensure consistency and comparability between samples.

Figure 2. Linear Cutting Machine, where "A" shows the potash rock block cast into the metal box, the red square encompasses the location of the pick within the dust curtain, the green arrow shows the movement of the box under the stationary pick to generate cuts, the white arrows indicate sideways movement of box to index the pick for the next cut, and the yellow arrows show the movement of the frame to control the penetration of cuts.

Dust collection setup

Two collection methods were used to obtain representative samples of dust generated from cutting rock. The first method uses Dorr-Oliver cyclones with a 50 percent cut point of 4µm aerodynamic diameter particles. The second method uses a vacuum (shop-vac) to collect the heavier particles left behind along the line of cut (crushed zone under the bit) on the surface of the rock after each cut. The particles collected with the vacuum are the fine materials that would be transported into downstream operations if the cuts were performed in a real mine.

The 10mm Dorr-Oliver cyclones remove larger airborne particles and deposits the respirable particles onto 37 mm diameter polycarbonate (PC) filters and 37 mm diameter PVC filters. Four cyclones inside the dust curtain were equidistant and evenly spaced around the pick to collect dust with the various filters. Polycarbonate filters are used for this experiment because the substrate is best suited to analyze particles in a scanning electron microscope [23][24]. PVC filters are used to obtain the concentration and mineralogy because the material has a stable weight and high collection efficiency [25][26][27][28]. The cyclones were connected with Tygon® tubing to air pumps running at 1.7 liters per minute, the recommended flow rate to use for maximizing collection efficiency [29]. Due to humidity changing the collection efficiency of cyclones, tests were conducted within a range that does not affect collection efficiency, which was between 20% and 30% humidity [30][31][32][33].

The cyclones and pumps are integrated within an automated dust collection system as seen in Figure 3. This system eliminates human error in sampling dust particles during full scale cutting tests and additionally clears out dust from prior cuts to flush out the system. With a laser measuring the displacement of the rock box, the data interface uses the laser readings to open and close the electric ball valves. This controls when the pumps draw in air to collect dust and additionally when the flushing system turns on to purge out dust after a cut. The automated dust collection system ensures consistency and therefore, comparability, between dusts generated with the various picks. Lastly, a rotameter is used to verify pump flow rates before and after rock cutting and a real-time concentration monitor is used to ensure the flush system removes all particles in the dust curtain before the next cut begins.

Figure 3. Dust collection system A) Data acquisition interface and power unit that controls when dust is collected and flushed out of the system, B) Solenoid ball valves to control the air flow through the cyclones, C) Pumps running at 1.7 liters per minute, D) Real-time dust concentration monitor, E) Rotameter placed in-line before testing to ensure pump is running at 1.7 liters per minute and re-installed after dust collection to measure pump flow rate post testing.

The cyclones are installed as close to the pick tip as possible inside the dust curtain and connected via Tygon® tubing to the pumps outside the dust curtain with the automated dust collection. The dust curtain is used to keep the generated dusts in a set volumetric space for collection and to keep outside unrepresentative dusts from being collected. With this, the ambient air within the dust curtain is collected before testing to ensure the air inside the dust curtain is clear of outside pollutants.

It should be noted that this test setup is not intended to measure the absolute volume of dust in the air. Rather it is a setting that allows for measurement of dust at each test setting for comparative analysis. Therefore, any possible errors in measurement relative to the actual field operations in mine settings are not going to impact the results, since the consistent measurement of the airborne dust and fines generated will allow for objective comparison between results for different bit wear conditions.

Pick wear quantification

Three radial bits were used for experimentation with a new, moderately worn, and severely worn wear level. They were all the same model bits that were used in full-scale borer miner units in underground potash mines in Canada. The moderately worn and the worn picks were previously used in the operation to cut potash. The worn pick was used at the external position (gage area) where they cover more footage for more cuts on the machine compared to the moderately worn pick.

To quantify the wear, the tip height and tip width were measured. Pick tip height is measured from the insertion ledge near the base to the top of the tip. Additionally, the pick tip width is measured across the tip when looking directly at the tip from the front view. The new pick, never previously used to cut rock, had the longest tip height and most narrow tip width, the worn pick had the shortest dimensions, and the moderately worn pick had dimensions between the two as seen in Figure 4. The height and width dimensions agree with the amount of wear on each pick. For example, as the pick wear increases, the tip height decreases and the tip width increases [34].

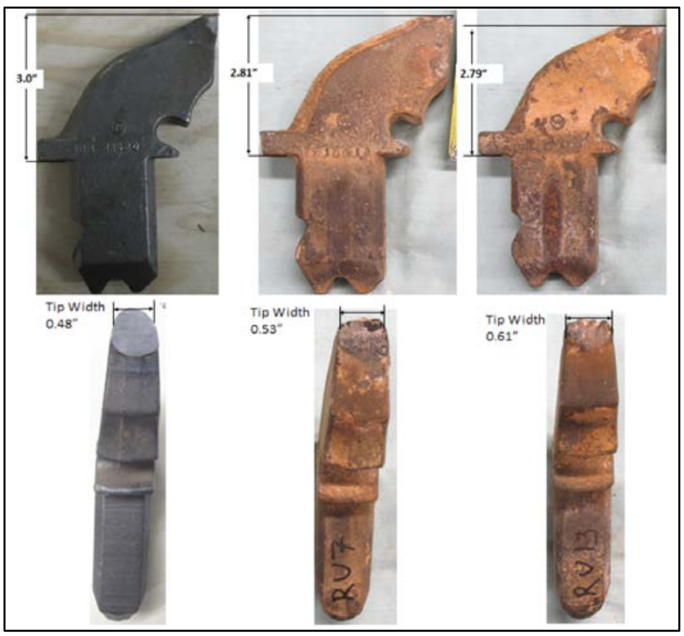

Figure 4. Pick tip heights in the top row and pick tip widths in the lower row for the new (left), moderately worn (middle), and severely worn (right) picks used in the full scale cutting.

Characterization of dust particles

Three overarching characteristic studies were performed on the respirable dust samples collected via the cyclones and one characteristic study was performed on the fine materials collected via the vacuum. Industry standard, particle shape, and size distribution analyses were performed on the respirable samples collected with the cyclones and the size distribution was performed on the fine materials collected from the rock sample surface.

NMAM 0600 and 7500 standards

The procedures prescribed by the NIOSH Manual of Analytical Methods (NMAM) 0600 (particulates not otherwise regulated, respirable) and NMAM 7500 (silica, crystalline, by XRD, filter deposition) were performed on the dust generated. MSHA uses these standard experiments to evaluate worker exposure limits and guide dust control decisions in the work place. The NMAM 0600 reveals the concentration of dust a worker is exposed to over a specific amount of time and the NMAM 7500 reveals the hazardous minerals a worker is exposed to over the same amount of time. Overall concentration exposures and mineral levels are important to know because workplaces need to abide to specific exposure concentration and mineral limit levels [35][36].

For these experiments, standard pre-weighted PVC filter cassettes were obtained from an outside lab. After dust collection, the filter cassettes were sent back to the lab for the standard tests to be conducted.

Particle shapes

The shapes of the dust particles are analyzed because this is one parameter that can influence the negative effect on human respiratory health [13]. For example, long and narrow particles that are smaller than 10µm in aerodynamic diameter, such as asbestos with an aspect ratio of 3 or greater, can readily be trapped in the lungs compared to more round particles [37][38][39][40]. Or, particles with geometric shapes ranging from spheres to cylinders will have different dynamic shape factors, which influence the speed at which the particle settles [41]. Therefore, the roundness and aspect ratio were calculated for particles less than 10µm aerodynamic diameter. Additionally, roughness, or the undulations along the perimeters, is calculated because it is possible that the shape's ruggedness can give the particle a different dynamic shape factor. With changing dynamic shape factors, it is possible that the particles will travel differently through the respiratory system [41] and could cause different health effects.

To determine the particle shapes, a field emission scanning electron microscope (FE-SEM) and image analysis program were used to take and process images from the PC filter surfaces. A Tescan FE-SEM at a voltage of 15 kV and back scattering electron (BSE) detection was used to obtain images. Then, Clemex Vision PE® software was used to process the images, detect particles, and perform calculations of roundness, aspect ratio, and roughness of particles. The Clemex Vision PE® software was programed to detect the particles with binarization by gray thresholding [42][43][44] to distinguish the difference between particles and the background. The process moving from an SEM image, to grey thresholding, to highlighting individual particles is shown in Figure 5. Other commands were also added to the program, such as bridging and object transfer, which separates particles that are clumped together and removes particles intersecting the edge of the image during detection, respectively.

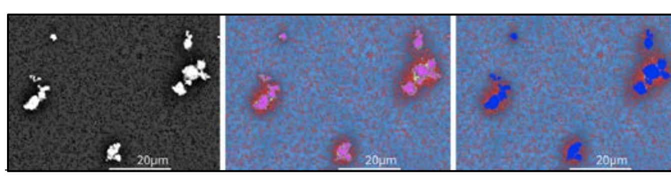

Figure 5. Raw SEM image (left), the image under grey thresholding (middle), and the program identifying and highlighting individual particles in blue (right) that will then be analyzed for shape features.

Particle roundness is calculated to determine how close to a perfect circle the particle of interest is via equation (1). Particle aspect ratio is calculated to determine the elongation of particles via equation (2). Particle roughness is calculated to determine the smoothness of the particle perimeter via equation (3). Convex perimeter is used to determine the particle roughness, where the convex perimeter is the perimeter of the object if a rubber band were placed around the particle, as shown in equation (4). With this, *length* is the longest measurement across an object, *width* is the shortest distance measured across an object [42].

$$\text{Roundness} = \frac{4\ (\text{area})}{\pi\ (\text{length})^2} \qquad (1)$$

$$\text{Aspect Ratio} = \frac{\text{length}}{\text{width}} \quad (2)$$

$$\text{Roughness} = \frac{\text{ConvexPerimeter}}{\text{Perimeter}} \quad (3)$$

$$\text{ConvexPerimeter} = \sum \text{ferets}\left[2\tan\left(\frac{\pi}{2(\text{number of ferets})}\right)\right] \quad (4)$$

Particle size distribution

The size distributions of respirable particles and fine materials were analyzed because the size of the particle a mine worker inhales can cause different health effects. For example, inhalable particles between 100µm to 10µm in aerodynamic diameter become trapped in the nose, thoracic particles less than 10µm become trapped in the region of the lungs where the bronchiole reside, and respirable particles less than 4µm are able to reach the region of the lungs where the alveoli reside [41]. The deeper into the lungs that silica particles penetrate, such as particles reaching the alveolar region, the more dangerous they can become to human health [35].

Using the images obtained from the FE-SEM and the Clemex image analysis program, all the individual particles detected on the PC filters were also measured for physical diameter. Because not all particles are perfectly round, the circular diameter is measured and calculated as if the object were a 2D shape as seen in equation (5). These physical diameters were then converted to aerodynamic diameters with the aerodynamic diameter conversion equation (6), which included factoring in the slip correction factor and Cunningham correction factors as seen in equations (7) through (9) [41]. Size distribution curves are generated with the aerodynamic diameter values.

$$\text{circular diameter} = d_p = 2 \times \sqrt{\frac{A}{\pi}} \quad (5)$$

$$\text{aerodynamic diameter with slip correction} = d_a = d_p\left(\frac{C_{dp}}{C_{da}}\right)^{0.5}\left(\frac{\rho_p}{\rho_0 \times \chi}\right)^{0.5} \quad (6)$$

$$\text{Cunningham correction factor} = C_{dp} = 1 + \frac{(6.21 \times 10^{-4})T}{d_p} \quad (7)$$

$$\text{Cunningham correction factor} = C_{da} = 1 + \frac{(6.21 \times 10^{-4})T}{d_{a,\ \text{no slip}}} \quad (8)$$

$$\text{aerodynamic diameter with slip correction} = d_{a,\text{no slip}} = d_p \times \sqrt{\frac{\rho_p}{\rho_0 \times \chi}} \quad (9)$$

Where

A = area
d_p = physical diameter of particle measured
T = temperature = 293K = 20˚C
ρ_p = density of potash particle = 2,400 kg/m^3
ρ_0 = density of water = 1,000 kg/m^3
χ = dynamic shape factor = 1.36 for quartz [41]

The fines left behind on the surface of the rock after each cut were collected with a five-gallon shop vacuum for size distribution analysis. This material was collected because it can pose health issues in downstream operations during transport or at transfer drop points when the material can become airborne. A Microtrac FLEX instrument that uses laser diffraction was used to obtain the physical particle size distribution for the fines. As described in section 2.4.3.1, the physical diameters obtained were converted to aerodynamic diameters and then analyzed for size distribution.

TEST RESULTS

NMAM 0600 and 7500 standards

Both the NMAM 0600 and NMAM 7500 procedures were followed for the dust samples obtained from full scale cutting tests using new, moderately worn, and severely worn bits. The NMAM 0600 results include the concentration of dust normalized to the amount of time that the respective pump was running. Concentration is given as micrograms per minute of pump time. The NMAM 7500 results include the mineralization in amounts of cristobalite, quartz, and tridymite present in each sample in units of micrograms per sample. Results for the NMAM standard tests are presented in Table 1.

It should be noted that NMAM 7500 is focused on the mineralogy of the dust with focus on three compounds that have severe and common impact on the respiratory system. It is most suitable for comparing different jobsites with various mineralogy of the rock that is being mined. However, in the initial phases of testing in this study, the potash samples cast in specialized grout do not necessarily represent a variety of mineral content.

Table 1. NMAM 0600 and NMAM 7500 standard results for the dust generated with the new, moderately worn, and severely worn picks.

Analysis	Result	New Pick	Moderately Worn Pick	Worn Pick
NMAM 0600	Concentration	μg/min	μg/min	μg/min
		4.82	32.00	15.00
NMAM 7500		μg/sample	μg/sample	μg/sample
	Cristobalite	0	0	0
	Quartz	0	43	31
	Tridymite	0	0	0

Particle shapes

The roundness, roughness, and aspect ratio of the individual respirable particles generated from new, moderately worn, and severely worn cutting tests were analyzed. FE-SEM images of the particles were run through the image analysis program to identify individual particles and perform the shape calculations as discussed in section 2.4.2. Twenty FE-SEM images equally spaced apart on the PC filters were obtained for all the dust samples correlating to each pick wear. 159 particles were identified on the samples from testing with new bit, 1593 from the moderately worn bit, and 397 from the severely worn bit. A sample of the FE-SEM images from each pick wear are shown in Figure 6.

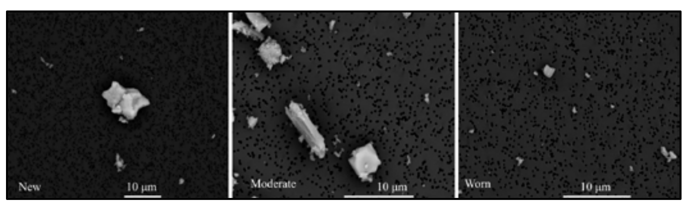

Figure 6. An example of the FE-SEM images obtained from the PC filters where respirable particles were captured and later analyzed for roundness, roughness, and aspect ratio.

The histograms presented in Figure 7 reveal the particle shape results from the identified particles. Roundness values of one indicate an overall round shape. From this value, the deviation from a round shape can be further analyzed in the roughness, or how rugged the edges are, and the aspect ratio, or how elongated the particle is. Roughness values of one indicate smooth edges and aspect ratio of one indicates a square, or compact particle.

Size distribution

The size distributions of respirable particles were determined from the images obtained by FE-SEM as discussed in section 2.4.3. Figure 8 shows the results for the aerodynamic diameter size distribution for the new, moderately worn, and severely worn pick during full scale cutting tests. The mean particle aerodynamic diameter is 1.2µm for the new pick, 0.8µm for the moderate pick, and 0.7µm for the worn pick.

A size distribution analysis was generated with the Microtrac FLEX laser diffraction instrument for the material that would become downstream fines in an industry setting. Figure 9 presents the aerodynamic diameter size distributions for dusts generated with the new, moderately worn, and severely worn picks.

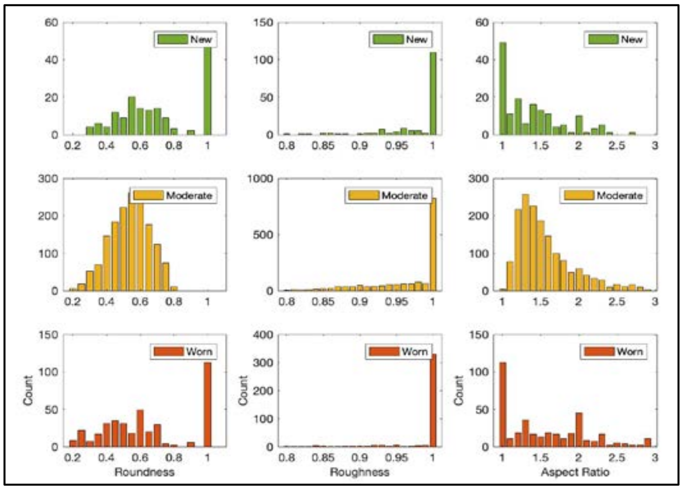

Figure 7. Histogram results for the roundness, roughness, and aspect ratio of the particles generated from full scale cutting tests with new, moderately worn, and severely worn picks.

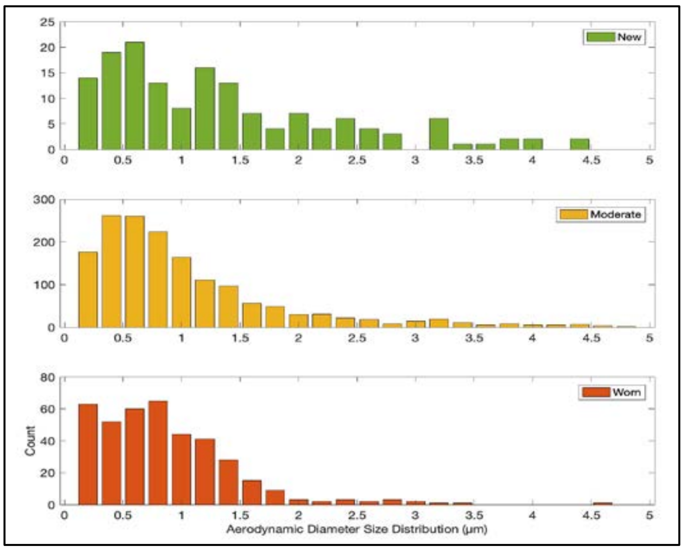

Figure 8. Histograms of the aerodynamic diameter size distributions of particles generated from cutting with new, moderately worn, and severely worn pick tips.

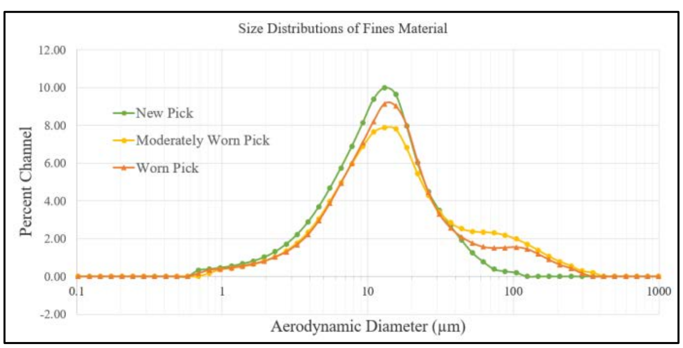

Figure 9. Size distribution curves for the fine dust particles that could pose health issues in downstream operations when handled or transferred.

DISCUSSION

NMAM 0600 and 7500 standards

The NMAM 0600 results for the new, moderately worn, and severely worn picks reveal that the moderately worn pick generated the highest amount of dust and the new pick generated the least amount of dust. This is confirmed by the FE-SEM analysis of the PC filters where 1593, 396, and 159 particles were detected for the samples collected with the moderate, severely worn, and new bit respectively, where each test had the same number of cuts.

Concrete recommendations to mining and tunneling operations cannot be made on which pick generates the most dangerous dust to workers because the results obtained in full scale cutting are limited. However, for these laboratory tests in the experimental environment, the dust generated from the moderately worn pick could be considered the most dangerous to human health because the moderate pick generated the highest concentration of dust particles less than 10μm in aerodynamic diameter.

The lower number of particles in the case of the fully worn pick compared to the moderately worn pick could be attributed to the shaping of the bit in the direction of cutting by having a smaller area. However, from a practical point of view, the worn bit has lower gage length, meaning that the bit body and bit block likely come to contact with the rock and higher fines are generated by such contact. Hence, the bit should be changed before becoming fully worn which, despite the limited testing results, can eliminate generation of higher fines and respirable dust in the underground environment.

The NMAM 7500 results simply show that there are trace amount of quartz from some of the samples, which could potentially harm workers. Because this test is more suitable for comparing jobsites, results were not further analyzed.

Particle shapes

Analyzing the histograms for the roundness values, the moderately worn pick rarely generated particles that were circular shaped (where a roundness value of one indicates uniformly shaped particle). The moderately worn pick instead generated longer, oblong, particles as confirmed in the aspect ratio values favoring values greater than one. On the other hand, the aspect ratios of samples obtained when using new and severely worn bits show a different trend in particle shapes, which reveal more round particles.

The histograms in Figure 7 show that the roundness, roughness, and aspect ratio are similar between the samples of dust collected when using the new pick and the severely worn pick. Meanwhile, there is a difference in the roundness and aspect ratio characteristics of the moderate pick when compared to the other two. The Kolmogorov-Smirnov statistical test (KS test) was performed between data sets to test the hypothesis that the distributions of particle shapes generated from the moderate pick is the same as the distribution from the new and severely worn pick. A significance level of 0.05 was used in the statistical analysis. Therefore, p-values below 0.05 provide strong statistical evidence to reject the hypothesis test.

The KS tests provide evidence that there is a difference between the moderate pick distribution when compared to the new pick and severely worn pick distributions for roundness, aspect ratio, and roughness parameters. The p-values obtained for the distributions compared between the moderately worn pick to the other picks were all below the 0.05 threshold. Additionally, when comparing the new and severely worn pick distributions, KS test p-values all at or near the 0.05 threshold provide strong evidence that the new and worn picks generate particles of similar shape characteristics.

The results show that the moderately worn pick generated particles that are longer in shape compared to the new pick and fully worn pick. If this trend is proven to be true across various bit types in further studies and confirmed in future experiments, it is possible that the moderately worn bit would be most dangerous to exposure. As noted before, the particle shapes in the case of new and worn bit could be a function of the profile of the bit in the direction of cutting and low cutting forces. If this is true, a change in the bit configuration could also aid in reducing dust issues during the life of a cutting tool to minimize generated dust and aspect ratios.

Size distribution

The size distributions of respirable particles for all three pick types favor particles less than 2μm in aerodynamic diameter as seen in

Figure 8. The aerodynamic diameter mean values for the datasets are 0.7µm, 0.8µm, and 1.2µm, for new, moderate, and severely worn picks respectively. With this, the dataset means were compared with Student's t-tests to see similarities in the mean values with a 0.05 p-value threshold. No p-values were above the threshold, therefore indicating strong evidence that all the datasets are different from one another.

Although the means of all the datasets are statistically different, the dust generated in rock excavation with each state of bit wear contain a majority of particles that can penetrate deep into the lungs. All bits could be considered dangerous to human health if not controlled or contained because they all generate respirable-size particles.

Figure 9 shows that all the measured particle size distributions for the material collected after full scale cutting tests are similar between the new, moderate, and severely worn pick conditions. Each distribution is single modal, with the peak around 15µm in the inhalable region. The moderately worn pick generated slightly more particles in the 50µm to 100µm diameter range when compared to the dust sized generated by the severely worn and new picks.

All picks can present a hazard in downstream operations because all picks generate similar size distributions of fines material that contain thoracic and respirable sized particles. These particles can become airborne during transport, transfer, or drop locations and can be breathed in further downstream to potentially cause health issues.

OBSERVATIONS

A review of the test results reveals strong tendency in dust and fine generations to be linked to the bit tip geometry. This has been observed by previous studies where the amount of dust generated in fines is linked to the cutting profile of the tool [45][46][47][34][48][49]. Therefore, instead of viewing the picks as new, moderately worn, and severely worn in relation to the tip for these experiments, the bits should be categorized by geometric tip shape for evaluating their potential for dust generation. For example, the new pick could be viewed as a sharp pick tip, the moderate pick could be viewed as a blunt pick tip, and the severely worn pick could be viewed as an undulating sharp pick tip that is formed by the rock during the wear process.

With this, the surface areas of the pick tips were measured 5mm down from the highest point to observe how dust characteristics change in relation to bluntness. The most blunt pick, or the moderately worn pick, has the most surface area exposed during cutting. This pick also generated the highest concentration of dust and the most oblong particle shapes. As seen in Figure 10, the pick tip surface areas exposed to rock are plotted with the various concentration measures obtained. Concentrations for tests with penetration depths at 0.6" and 1.5" were also added, where zero concentrations should be neglected because they indicate no dust was collected due to collection failure. The figure shows that there is a correlation between pick tip surface area and concentration. With this, for these laboratory experiments, the blunter picks are potentially more dangerous to human health.

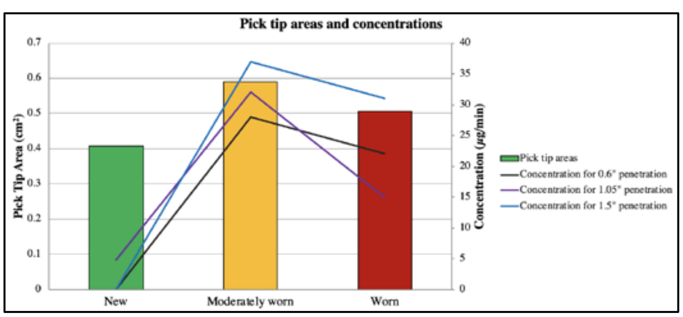

Figure 10. The surface area of the pick tips exposed to rock as measured 5mm down from the highest point of the pick tip.

The wear pattern of the bits should be observed during operation and if the continued wear leads to wider tip and bluntness, operators could expect a higher generation of dust with higher aspect ratio particles. It should be noted that the results presented in this article are preliminary and based on limited initial testing. Results are not considered universally applicable to all rock excavation scenarios. Additional testing with different picks and rock types are underway to evaluate the impact of cutting tool wear on the characteristics of dust and subsequent testing will be presented in upcoming publications.

CONCLUSION

Dust exposures can become more dangerous to workers in hard rock cutting environments in terms of particle concentration, mineralogy, shape, and size distribution depending on the geometry of the radial pick tip. In terms of concentration and particle shape, picks with one sharp tip (new picks) or picks reshaped in the process of cutting that form a narrow tip configuration (severely worn picks) are potentially less dangerous to workers because they generate lower concentrations of dust and create more round-shaped particles. On the other hand, picks with blunt tips (moderately worn picks or severely worn picks where the wear pattern makes a blunt configuration) are possibly the most dangerous to workers because they generate higher concentrations of dust and generate more elongated particles. If future experiments confirm this trend in dust characteristics, then dust mitigation systems should be considered to mitigate the amount and shape of respirable dust particles that are generated by radial bits with blunting tips.

In terms of the particle size distributions, all the picks used in these preliminary laboratory tests generated airborne particle sizes less than 2µm, which are respirable and potentially dangerous to workers. Further experiments are underway to confirm this trend, although dust mitigation systems should be in place no matter what geometric tip is cutting rock. This is because common practice is to replace only the worn picks on the cutter head where a unit most likely has a mix of new and worn bits at any given time. Additionally, all picks in the laboratory generated fines that contain thoracic and respirable sized particles, which could be inhaled and cause respiratory health problems. This is the reason and confirms current practices in underground mining and construction where dust suppression systems are used to limit dust exposures.

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