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Collecting representative dust samples: A comparison of various sampling methods in underground coal mines

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ABSTRACT

Former methods used in the U.S. to assess hazardous and explosible coal dust date back to the 1950s. As mining technologies advanced, so too have the hazards. Given the results of the recent coal dust particle size survey and full-scale experimental mine explosion tests, the National Institute for Occupational Safety and Health (NIOSH) recommended a new minimum standard, in the absence of background methane, of 80% total incombustible content (TIC) be required in the intake airways of bituminous coal mines, replacing the previous 65% TIC requirement. Most important to monitoring and maintaining the 80% TIC is the ability to effectively collect and analyze representative dust samples that would likely disperse and participate in dust explosion propagation. Research has shown that dust suspended on elevated surfaces is usually finer, more reactive, and more readily dispersible while floor deposits of dust are generally coarser and more difficult to disperse given the same blast of air. The roof, rib, and floor portions of the dust samples were collected and analyzed for incombustible content separately and the results were compared to a band sample of the roof, rib, and floor components. Results indicate that the roof and rib dust samples should be kept separate from floor dust samples and considered individually for analyses. The various experimental collection methods are detailed along with preferred sampling approaches that improve the detectability of potentially hazardous accumulations of explosible dust.

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1. Introduction

Research has shown conclusively that as the average size of coal dust particles decreases, the explosion hazard increases (Cybulski, 1975; Michelis, 1998; Cain, 2003; NIOSH, 2010). Recent dust survey results show that the coal dust found in mines today is much finer than in mines of the 1920s (Sapko et al., 2007). Given the results of the recent coal dust particle size survey and subsequent full-scale Lake Lynn Experimental Mine (LLEM) explosion tests, the National Institute for Occupational Safety and Health (NIOSH) recommended a new standard of 80% total incombustible content (TIC) be required in the intake airways of bituminous coal mines to replace the existing 65% TIC requirement (NIOSH, 2010). To determine compliance with the 80% TIC requirement, mine operators and MSHA inspectors regularly collect dust mixtures at various distances along mine entries, measure the TIC, and compare the results to the minimum 80% TIC requirement. The sampling method of collecting a combined band sample using a brush and pan to gather an approximately 15-cm (6-in) wide strip of dust from the roof, ribs, and floor has evolved over many years. With the implementation of the new 80% TIC requirement and with increased mechanization, is the current band sample approach still the best method to detect potential dangerous accumulation of explosible coal and rock dust mixtures?

Owings et al. (1940) stated "Because of differences in quantity, fineness, and composition, samples should be taken in pairs at any one place; one from the roadway and one from the roof and ribs. A true picture of the dust conditions cannot be obtained otherwise" and "…Tests indicate that essentially no amount of rock dust on the floor will stop an explosion traveling through the very finely divided coal dust dislodged from overhead surfaces".

Saltsman and Grumer (1975) indicated that "the roof-rib noncombustible content cannot be predicted from or indirectly equated to, its corresponding 15-cm (6-in) floor sample" and "If the combustible content of the rib-roof dust is considered hazardous, it should be analyzed separately." It was noted that the roof-rib weight fractions of the band samples were small enough to have little effect on the TIC of the total band sample and should be analyzed separately. Nagy et al. (1965) originally stated and Sapko et al. (1987) later confirmed that small amounts of float coal dust

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on the roof and ribs plays a key role in explosion propagation independent of the TIC on the floor.

The Mine Safety and Health Administration (MSHA) collected mine dust samples at least every 150 m (500 ft) of new development from mines within all eleven bituminous Coal Mine Safety and Health Districts to assess explosible coal dust conditions. The dust samples were routinely collected by MSHA mine inspectors to assess compliance with 30 CFR 75.403. The sampling method required a perimeter band sample to be collected and combined from the roof, rib, and up to 2.5 cm (1 in) deep from the floor. The samples were then sent to the MSHA National Air and Gas Laboratory at Mt. Hope, WV, and analyzed for total incombustible content (TIC). The TIC included measurements of the moisture in the as-received samples, the ash in the coal, and the rock dust content. In 2013, MSHA proposed and enacted a sampling protocol change to allow for the collection of roof and rib sample as one sample and a separate collection of a 3-mm ($^1/_8$-in) deep floor sample. MSHA states:

> Based on inspectors evaluation band samples may be split at any location where coal dust is visible on the roof, ribs, structures or suspended items. Issue a citation if either of these samples from a band are non-compliant with the incombustible content requirements in § 75.403. In areas where the roof/ribs/and mine floor are uniformly rock dusted only a single band sample is needed (MSHA, 2013).

This protocol is similar to that of New South Wales and still allows for the roof, rib, and floor dust to be mixed and collected as one combined band sample based upon visual inspection and inspector discretion (NSW, 2006). However, Nagy (1981) has stated "An observer cannot estimate with precision the exact percentage of incombustible in a mine dust sample. The difference between visual estimation and chemical analysis ranged from −17.5 to +27.5 percentage points of incombustible for rib and roof samples (102 samples). The difference between visual estimation and chemical analysis ranged from −22.5 to +22.5 percentage points of incombustible for floor samples (107 samples)." Therefore, is an inspector's visual discretion adequate for determining if the roof/rib dust can or should be mixed with the floor dust for analysis?

2. Experiments

2.1. Former methods for collection of representative dust samples

Prior to 2013, sampling practices for determining compliance required samples be collected at least every 150 m (500 ft) of mine entry (MSHA, 2008) as the mine face advanced. An inspector would use a brush to collect the rock dust and coal dust present on the roof, rib, and up to 2.5 cm (1-in) deep on the floor. The brush and pan method is detailed later for the rib and floor. The brush and pan method is used by MSHA to collect a dust sample from the roof also. The roof, rib, and floor sample would be combined together as a perimeter band sample. The use of ground control fixtures such as mesh could interfere with the collection of a representative band sample from the ribs and roof. With the mesh on the ribs, it could be difficult for inspectors to brush the dust from the ribs into a pan for sample collection. The space between the mesh and strata could allow the dust to fall behind the mesh or to be swept away by the ventilation airflow rather than to be collected. During previous sampling studies, the dust on the roof was sampled only in mines with a roof that could be accessed without the aid of a ladder or extended sampling equipment. In mines where the roof was beyond reach, a sample from the roof was not collected. In high roof mines, it was acceptable to take a sample of the floor and ribs to the maximum height that it could be done safely and practically (MSHA, 2008). Therefore if coal dust were present on the roof and rib and/or any mesh support above the reach of the inspector, in these instances, it would not be collected for analysis and a potential explosion hazard could go undetected. Also, when combining a limited quantity roof and rib sample with a 2.5 cm deep floor dust sample, the potential coal dust explosion hazard could easily go undetected if the floor was preferentially rock dusted.

The sampling methods have remained the same except the new MSHA sampling protocol (MSHA, 2013) allows for the roof and rib portions to be collected and analyzed separately from the floor portion based upon a visual evaluation of the uniformity of the rock dust application.

2.2. Sampling techniques

Various sampling techniques were evaluated in the NIOSH Office of Mine Safety and Health Research (OMSHR) Bruceton Experimental Mine in an attempt to obtain the best and most representative dust sample from an entry. Rock dust was generously applied with a pneumatic rock duster to the entry's roof, ribs, and floor. A fine layer of Pittsburgh pulverized coal (PPC) dust (coal dust containing ~80% particles <75 μm) was then applied in the same manner. The techniques that were deemed most successful are described in more length in the following 2.3 Field sampling protocol section.

2.3. Field sampling protocol

A total of nine mines were visited by NIOSH researchers to include different mining methods, coal seams, and conditions. On each visit, a four- or five-person team accompanied mine personnel to the advancing development section or longwall. At each sample location, a series of samples would be collected from the roof, ribs, and floor with each portion of the entry being collected and analyzed separately. In other words, the rib dust was not mixed with the roof dust or the floor dust to create an overall perimeter "band" sample.

All of the samples were passed through a 10-mesh sieve within the mine before transferring the sample to the NIOSH laboratory. Once at the laboratory, the sample bags were opened so the samples could air dry until constant mass was achieved. The samples were passed through a 20-mesh sieve and then weighed to obtain the total amount of sample collected. After the samples were weighed, a low temperature ashing (LTA) analysis was conducted (Cain, 2003). Only the percent incombustible content (% IC) is reported – not the % as-received moisture.

2.4. Roof samples

At each sample location, a roof sample was collected using a 20-cm (8-in) diameter bowl fitted with a 14-cm (5.5 in) wide brush in the center (Fig. 1). The 14-cm wide brush was inserted and affixed to the bowl so that the approximately 2.5 cm long bristles of half of the brush extended above the bowl lip. A threaded mop handle bracket was attached to the bottom of the bowl. This allowed the user to hold the bowl by the handle and drag the bristles across the roof. The bowl was then able to collect the dust dispersed by the bristles. The threaded head and handle could also be fitted with a telescoping handle to allow for samplings in areas beyond a user's reach (Fig. 2). Even in entries with high ventilation velocities and/or locations above belt conveyors, 14-cm wide samples of dust were successfully collected with minimum dust loss using the bowl with brush sampling device. If the first 14-cm wide pass did not appear

Fig. 1. Bowl and brush configuration mounted on a mop head to collect roof samples.

Fig. 2. Collecting a roof sample using the bowl and brush with a handle.

to collect sufficient sample to analyze using the LTA method (requires a minimum of 1 g of dust), a second or third pass of the roof was made to collect additional dust. The number of passes was noted on the sample bag.

2.5. Rib samples

Rib samples were collected either by using the 15-cm wide pan and 10-cm (4-in) wide brush (Fig. 3) or a 3-cm (1.25-in) wide (diameter) scoop and 4-cm (1.5-in) wide brush (Fig. 4). The pan and brush arrangement is typically used when the ribs are easily accessible. However, when mesh is installed on the ribs, sampling by pan and brush is much more difficult and likely results in sample loss. As an enhanced technique to collect the meshed rib dust sample, the scoop fabricated from PVC pipe was used with the narrower brush. The scoop shaped end of the PVC pipe (right photograph of Fig. 4) was able to be inserted into the mesh openings to collect the dust from the rib as well as the dust located on the mesh. The dust would then fall through the PCV pipe and into the dust collection bag attached to the bottom of the pipe (left photograph of Fig. 4). If sufficient sample was not collected, another pass of the rib was made to collect additional dust and was noted on the sample bag.

Fig. 3. Brush and pan used for sample collection on ribs.

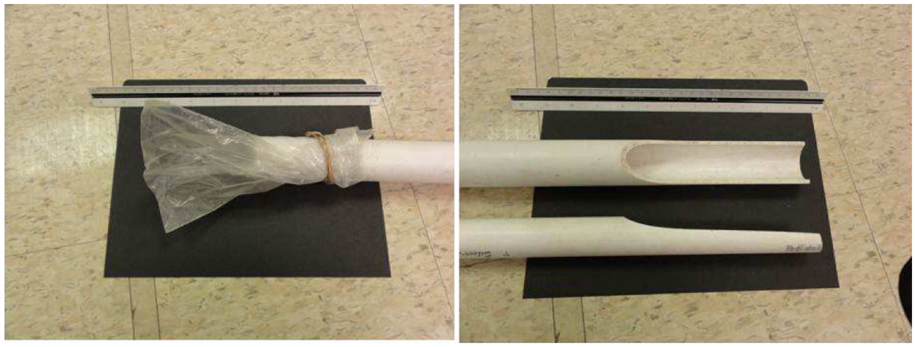

Fig. 4. Scoop used for sample collection from ribs with mesh.

2.6. Floor samples

During large-scale dust explosion testing at the LLEM in 2008, 13 sets of dust scouring measurements were collected. The dust scoured is indicative of the depth of dust participating in a developing dust explosion. Two parallel rails were filled with a coal dust/rock dust mixture and positioned in the entry with the dust leveled between the rails. Using a displacement gauge mounted on an aluminum bar, measurements were taken of the dust levels before and after the explosions. The dust scoured during an explosion ranged from 0.7 mm (0.03 in) to 2.6 mm (0.1 in) with an average of 1.7 mm (0.06 in) and a standard deviation of 0.5 mm (0.02 in). This is much less than the 25-mm depth that is specified in the MSHA band sampling procedures in effect at the time. Therefore, the current 25-mm sampling depth of dust does not represent the floor dust that would participate in initial explosion development. If there is a surface layer of coal dust, the band sample can be diluted with rock dust by sampling to a full depth of 25 mm, thereby giving a false sense of safety. A sample depth of 3 mm appears to better represent the depth of dust dispersed during the early stages of explosion development (Sapko et al., 1987; Harris et al., 2009).

A variety of methods was used for this study to collect the floor samples which included the brush and pan, a cheese planer, and a pump sampler. These different methods were able to collect samples at varying depths.

2.6.1. Brush and pan

The 10.2-cm wide brush and 15-cm wide pan were used to collect dust up to ~2.5 cm deep from the mine entry floor (Fig. 5). This was the previously accepted practice and equipment. After the full width of the mine entry was sampled, the dust was mixed, coned, and quartered (Fig. 6). This was required due to the size and amount of sample that could be collected. Some samples weighed as much as 2041 g (4.5 lb) before being mixed, coned, and quartered to reduce the amount of sample that was actually taken back to the laboratory. Theoretically, a sample could weigh ~23.3 kg (~51.5 lb) if a full inch depth of dust were collected across a 5.5-m (18-ft) wide entry.

Fig. 5. A brush and pan were used to collect dust from the floor up to 2.5 cm deep.

Fig. 6. Coning and quartering of the collected floor dust.

2.6.2. Cheese planer

Due to evidence from the full-scale LLEM explosion tests indicating that the top 3–6 mm ($^{1}/_{8}$ – ¼ in) of floor dust is scoured in the beginning stages of a propagating explosion, a cheese planer was used to collect the top 3 mm of dust from the entry floor (Fig. 7). However, the use of the cheese planer was not always feasible at each location. If a mine wetted the floor to control dust or if the floor contained numerous large pieces of coal and/or rock, then the cheese planer was not able to collect sufficient samples.

2.6.3. Pump samples

A vacuum pump sampler with a hose attachment was used to collect dust at 2.5-mm, 1.6-mm, and 0.8-mm (1/10-in, 1/16-in, and 1/32-in, respectively) depths. Due to the small diameter (50 mm), several "plugs" had to be taken in order to obtain sufficient quantities of dust for LTA evaluation and to fairly represent the entire entry width. The number of plugs in each sample bag was recorded. A sintered metal filter was used as the dust collection surface. The outer edge of the filter was raised and lowered to the desired

Fig. 7. A cheese planer is used to collect a 3-mm depth dust sample from the floor.

sampling depth by loosening an anchoring screw on the side of the hose and inserting "keys" of known thickness (2.5-mm, 1.6-mm, and 0.8-mm) and then retightening the screw. After energizing the pump, the filter was then placed into the dust on the floor (left photograph of Fig. 8). Using a straight-edged spatula, the dust was leveled with the outer edge of the filter (center photograph of Fig. 8). With the dust leveled and held against the filter by the vacuum suction, the filter anchoring screw was then loosened and the outer edge of the filter lowered so that the dust could empty into a sample collection bag (right photograph of Fig. 8). Large coal or rock particles on the floor prevented dust compaction on the collection surface. Note that the pump sampler was not used on the first two mine visits. This sampling technique was developed and tested at the laboratory only after the first two visits were completed.

2.7. Selection of sample locations

At each section, the first sampling site was located as close to the face as reasonably possible without interfering with production or presenting a safety hazard to either the sampling team or the mine personnel. These sampling sites were established so that the sample locations in all entries were at the same point relative to the advancing development section. Typically these points were situated so that the first location was just outby the conveyor belt feeder. In Fig. 9, the first sampling location in each entry is designated by the green number 1. Subsequent sample locations occurred 150 m (500 ft) from the previous location. Due to the limited time available for each mine study, samples were generally collected at three points within the same entry. As shown in Fig. 9, sample location 2 in entry 3 was 30 m (100 ft) from sample 1 and at the end of a series of dust pans set along the belt conveyor. Samples collected at sample locations 3 and 4 were 150 m (500 ft) and 300 m (1000 ft) from sample locations 1 in all three entries.

3. Results and discussion

There was some concern that the suggested dust sample locations would receive targeted rock dusting before the study since NIOSH personnel were conducting the dust sampling study based on the available schedule of the mine company. Out of 156 different locations and with 697 samples collected for analysis, 509 samples (73%) were equal to or greater than 80% IC. When examining the data in Table 1, the areas of the entry that were the hardest to attain 80% IC were the ribs (68% of the samples ≥80% IC). Upon examination of the floor samples by varying depths, it appears that the floors may have been recently dusted since the % IC-values increase with decreasing depth. However, it is important to note the pump sampler was only able to obtain samples at all depths in a limited number of instances, approximately 30 sample areas. This was due to insufficient rock dust on the floor to obtain a good filter-to-floor dust contact, numerous large pieces of rock/coal that interfered with the filter-to-floor dust contact, or the pump sampler was not available at the initial mine visits.

On the initial review of Table 1, one may assume that the roof, rib, and floor portions do not differ significantly from one another and that collecting one perimeter band sample from these entry locations would be acceptable. However, as can be seen in Fig. 10, there is a large scatter in the data when comparing the % IC from the rib samples, the 2.5-cm deep floor samples, and the 3-mm deep floor samples with the roof samples. If the samples were representative of each other, one would expect them to fall along the green "best fit" line. In fact, when a linear regression is performed, the R^2 is 0.01, 0.01, and 0.25 for the comparison of the roof samples to the 3-mm deep floor samples, the 2.5 cm deep floor samples, and the rib samples, respectively. This indicates a wide scatter of data and lack of correlation of the roof samples to the 3-mm deep floor samples, the 2.5-cm deep floor samples, and the rib samples.

When comparing the rib samples to the floor samples (Fig. 11), a similar pattern emerges. The R^2 is 0.13, 0.20, and 0.25 for the

Fig. 8. Pump sampler used to obtain dust samples 2.5-mm, 1.6-mm, and 0.8-mm deep.

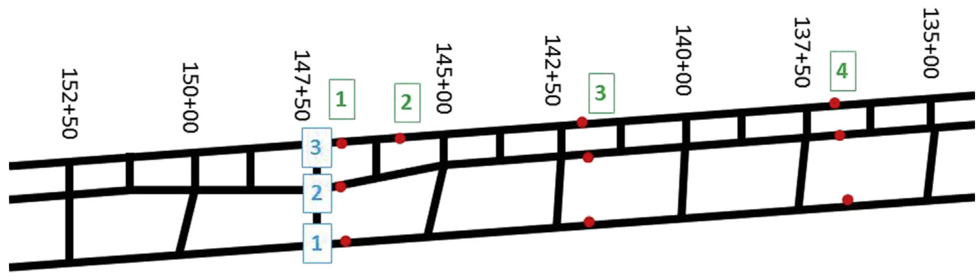

Fig. 9. Example of typical sample locations within an advancing mine section. The blue numbers indicate the mine entry number and the green numbers indicate the sample location along the mine entry.

Table 1
Summary of dust sample data collected at 9 mine field sites.

	Roof	Rib	Floor sample depths				
			25.4 mm	3.2 mm	2.5 mm	1.6 mm	0.8 mm
			1 in	1/8 in	1/10 in	1/16 in	1/32 in
Population (no.):	155	155	138	119	30	29	28
Mean (% IC):	83.8	82.3	83.3	85.7	88.9	91.7	92.9
Std. dev. (% IC):	15.6	16.0	15.5	13.9	11.3	9.7	8.2
Confidence limits (95% confidence):	±2.5	±2.5	±2.6	±2.5	±4.0	±3.5	±3.0
% of samples >80% IC:	70.3	68.4	72.5	73.9	86.7	89.7	92.9
% of samples <80% IC:	29.7	31.6	27.5	26.1	13.3	10.3	7.1

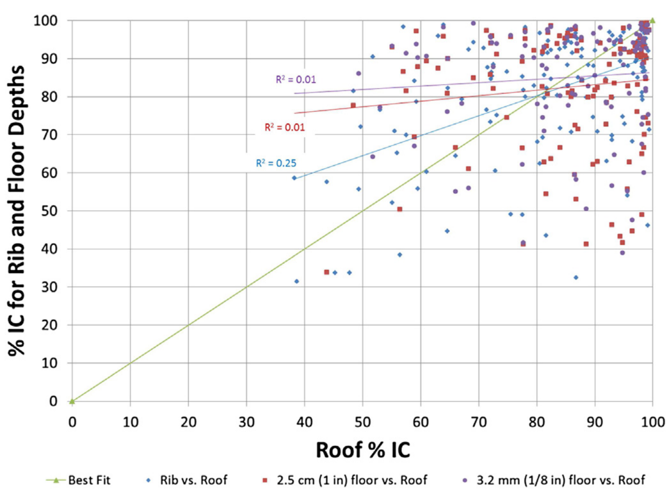

Fig. 10. Comparison of the rib samples, 2.5-cm deep floor samples, and 3-mm deep floor samples to the roof samples.

comparison of the rib samples to the 3-mm deep floor samples, the 2.5 cm deep floor samples, and the roof samples, respectively.

When comparing the 2.5-cm depth to the 3-mm depth, the R^2 is 0.77 (Fig. 12). Although less data is available, the R^2 for the sampling depths of 2.5-mm, 1.6-mm, and 0.8-mm are 0.74, 0.56, and 0.64 respectively. Although this demonstrates a correlation of the differing depths with the 2.5-cm depth, it is not strong. NIOSH researchers prefer collecting a more representative dust scour depth of 3 mm especially in areas where rock dusting may by cyclic and layering could occur. Also, a 0.8-mm depth would be necessary for detection of a potential float coal dust hazard.

Ideally, if the samples from each portion of the entry were representative of each other, then the differences between the samples would be 0% IC and the data points would fall along the green "best fit" line. Figs. 10 and 11 show quite a bit of scatter in the data whereas the data scatter in Fig. 12 appears to be less but this can be due to limited samples.

In Table 2, the differences calculated are the % IC values of the second sample subtracted from the first sample in each heading. For example, for the roof vs. rib column, the difference is the roof % IC − rib % IC. When examining the differences between samples, Table 2 shows the greatest variance occurred between the roof and the 2.5-cm deep samples which had a mean difference of 3.3% IC and a standard deviation of 19.3% IC. The best agreement was the 2.5-cm deep and 3-mm deep floor samples with a mean and standard deviation of −1.7% and 7.1% IC respectively. The negative values indicate that the 2.5-cm depth contained less % IC than the 3-mm depth on the floor. On average, the % ICs from the roof samples were higher than the % ICs from the rib samples or any of the floor samples. This may indicate the roof was better rock dusted than the ribs or floor or that the roof retained rock dust better and did not collect and hold coal dust as well. The % IC of the rib samples tended to be less than the roof samples and the 3-mm deep floor samples but more than the 2.5-cm deep floor samples. The 3-mm floor depth % IC tended to be higher than the 2.5-cm floor depth. The means in Table 2 are relatively small but it should be noted that the standard deviation of the samples' differences ranged from 7.1% IC to 19.3% IC. It is surprising to see that a roof dust sample contained 55.9% more IC than the corresponding 3-mm floor sample at that location. At another sample location, the 3-mm floor sample contained 52.7% more IC than the corresponding rib sample. Factors such as the material, geology, and integrity of the roof, entry use, and rib sloughage may affect this.

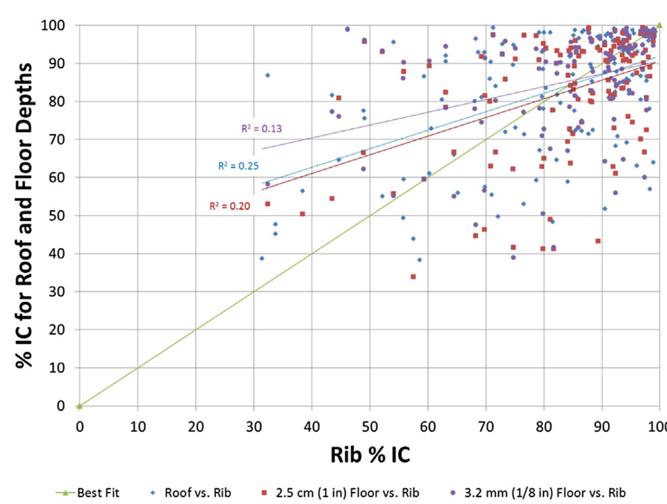

Fig. 11. Comparison of the roof samples, 2.5-cm deep floor samples, and 3-mm deep floor samples to the rib samples.

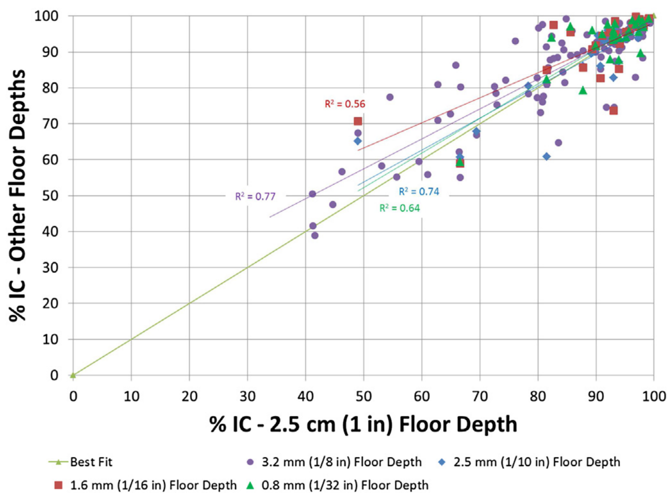

Fig. 12. Comparison of the 2.5-cm deep floor samples to the samples taken to depths of 3 mm, 2.5 mm, 1.6 mm, and 0.8 mm.

When examining the absolute differences between samples, Table 3 shows the greatest variance still occurred between the roof and the 2.5-cm deep floor samples which had a mean difference of 14.8% IC and a standard deviation of 12.9% IC. The best agreement (absolute difference % IC = 0) was the 2.5-cm deep and 3-mm deep floor samples with a mean and standard deviation of 4.9% and 5.4% IC respectively. Although this is the best agreement, the floors of the mine entries may be more uniformly mixed from haulage traffic or mining activity prior to the mine visit.

When considering the data in Tables 2 and 3, the mean in Table 2 is lower (−1.7) due to considering both positive and negative numbers which can be misleading in allowing one to believe the fit is better than what it is. By examining the absolute differences, it can be seen that the data scatter is indeed larger which better reflects the trends or lack of trends seen in Figs. 10–12.

Based upon the weight of sample gathered over a known surface area, the equivalent of a "band" sample and a combined roof/rib % IC was calculated. Table 4 lists the R^2 values of the different sample portions, including the calculated band and the roof/rib combined samples. When comparing the % IC of the band samples, the 2.5-cm deep floor sample dominates the band sample calculation (R^2 value of 0.86). Likewise, % IC of the rib samples dominates the rib/roof sample calculation (R^2 value of 0.86).

Table 2
Comparison of differences between roof samples, rib samples, 2.5-cm deep floor samples, and 3-mm deep floor samples.

	Difference					
	2.5 cm Floor vs. 3.2 mm floor	Roof vs rib	Roof vs. 2.5 cm floor	Roof vs. 3.2 mm floor	Rib vs. 2.5 cm floor	Rib vs. 3.2 mm floor
Population (no.):	112	146	123	107	126	109
Mean (% IC):	−1.7	1.3	3.3	0.4	1.3	−1.7
Std. dev. (% IC):	7.1	16.0	19.4	18.6	15.8	16.5
Confidence limits (95% confidence):	±1.3	±2.6	±3.4	±3.5	±2.8	±3.1
Maximum difference (% IC):	18.8	54.4	53.2	55.9	46.1	40.1
Minimum difference (% IC):	−22.9	−41.3	−38.0	−38.2	−46.6	−52.7

Table 3
Comparison of absolute differences between roof samples, rib samples, 2.5-cm deep floor samples, and 3-mm deep floor samples.

	Absolute difference					
	2.5 cm Floor vs. 3.2 mm floor	Roof vs rib	Roof vs. 2.5 cm floor	Roof vs. 3.2 mm floor	Rib vs. 2.5 cm floor	Rib vs. 3.2 mm floor
Population (no.):	112	146	123	107	126	109
Mean (% IC):	4.9	11.7	14.8	13.8	11.7	11.5
Std. dev. (% IC):	5.4	10.9	12.9	12.4	10.7	11.9
Confidence limits (95% confidence):	±1.0	±1.8	±2.3	±2.4	±1.9	±2.2
Maximum difference (% IC):	5.9	13.5	17.1	16.2	13.5	13.7
Minimum difference (% IC):	3.9	9.9	12.6	11.5	9.8	9.2

MSHA proposed and enacted a sampling protocol change to allow for the collection of roof and rib sample as one sample and collection of a 3-mm deep floor sample separately. However, MSHA inspectors can still combine the three portions into one band sample for analysis based upon visual inspection of uniform rock dusting. Even with the participating mine operators being aware well in advance of the NIOSH visit and purpose and possibly preparing the mine entries before the NIOSH study, this data suggests that the roof and ribs be kept separate from the floor for analysis.

Different portions of the sampling were compared to each other and to the band calculations to determine if correlations existed. For example, as seen in Table 4, the corresponding R^2 for the correlation of the calculated roof/rib sample with the 3-mm deep floor sample is 0.15 and it would therefore be advisable to analyze these two samples separately. However, MSHA still allows for band samples to be collected based on an inspector's visual determination. During the mine visits, the NIOSH researchers noted few instances of visible float coal dust at the sample locations. The decision whether to sample the location in separate increments or as a complete band sample could not be made reliably in the field. Given the previously stated observations and the data from this study, it is questionable whether visual assessment is adequate in assessing if dust samples should be collected separately from the roof, rib, and floor or collected together as a perimeter band sample (Nagy, 1981; Owings et al., 1940; Saltsman and Grumer, 1975; Sapko et al., 1987). The only verifiable method is to analyze roof/rib and floor samples separately.

Table 4
R^2 values of compared samples.

R^2	Sample portions	
0.22	Roof	Band
0.43	Rib	Band
0.66	3.2 mm floor	Band
0.86	2.5 cm floor	Band
0.49	Roof/rib	Band
0.25	Roof	Rib
0.01	Roof	3.2 mm floor
0.01	Roof	2.5 cm floor
0.13	Rib	3.2 mm floor
0.20	Rib	2.5 cm floor
0.77	3.2 mm floor	2.5 cm floor
0.48	Roof	Roof/rib
0.86	Rib	Roof/rib
0.15	3.2 mm floor	Roof/rib
0.19	2.5 cm floor	Roof/rib

4. Conclusions

The brush/bowl method successfully collected dry dust samples from the roof in all of the mines. It was able to easily and safely capture dust in high-roof mines and from the roof areas above conveyor belts. The brush/pan method still worked well when collecting rib samples. When mesh was installed on the ribs, the PVC scoop provided an alternative method to collect dust from the rib surface behind the mesh as well as the dust deposited on the mesh. The brush/pan method was the easiest to use when collecting dust samples from the floor but a light hand is required to obtain only the top 3 mm of dust. It was easier to collect the top 3 mm of floor dust with the cheese planer. However, larger bits of coal or rock can interfere with the dust collection. The plug sampler worked well to take samples of less than 1 mm. However, in order to obtain sufficient dust for analysis, several "plugs" were needed and the sampling became much more time consuming. As with the cheese planer, larger chips of coal or rock interfered with the sample collection and plug compaction.

Results of this study support the conclusions reached in previous studies by Owings et al. (1940), Saltsman and Grumer (1975), Nagy (1981), and Sapko et al. (1987) that indicate that the roof and rib dust samples should be kept separate from floor dust samples and considered individually for analyses. A correlation appears between the floor dust samples collected at varying depths which indicates some mixing may have occurred from mining activities. The practice of combining a sample depth of 2.5 cm from the floor overwhelms the roof and rib portions of the overall perimeter band sample. The presented data support the MSHA procedure change to allow the combined roof and rib sample be collected separately from the new 3-mm deep floor sample for a more representative sample. However, it is advisable that the roof and rib dust always be kept separate from the floor sample for analysis.

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