# Assessing support packs from an occupational hygiene perspective

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ABSTRACT: Cementitious grout support packs are usually assessed for their strength and durability from a safety perspective. Formulations of these packs range from cement mixed with water to resin-based formulations. Over time, these packs start to crumble and fine dust is released into the workplace atmosphere. This paper presents the outcomes of a pilot study that was undertaken to assess the crystalline silica content in the fine fraction of different support-pack materials. The bulk materials had a fine fraction of between 0.2% and 1.3%. However, the crystalline silica concentrations in the fine fractions were between 2.5% and 41.9%. The amount of crystalline silica is significant and loose dust that is made airborne over prolonged periods of time, may pose a considerable health threat to mine employees.

## 1 INTRODUCTION

Pumped cementitious grout packs are used in mines to support the hangingwall, controlling the rate of closure and to prevent the fall of ground (FoG). The cured cementitious grout is typically contained in a geotextile bag which adds the benefit of stiffening against lateral deformation under axial load (Skarbövig 2011). Since the 1960s advances have been made in the use and design of different types of supports (Daehnke et al. 2001). The main function of support packs is one of *safety*, i.e. to prevent physical injury or fatalities to mine employees in underground operations. However, as support packs crumble over time, fine dust is released into the workplace atmosphere. This paper reports on a pilot study that investigated the fine dust and crystalline silica that may be released over time from an occupational hygiene perspective.

## 2 BACKGROUND

Support packs in the mining industry are used to support the hangingwall from imminent collapse where the rock and/or soil have been excavated in mining activities. Mines generally use explosives to move the rock face while following the reef. As the mining activities move along with the reef, the unsupported hangingwall (roof) becomes a danger to mine employees because of the potential for rock falls. sFoG have consistently been a major contributor to mining accidents and fatalities over the past 10 years as shown in Figure 1 (Department of Mineral Resources, 2010). FoG contribute the most to mine injuries and fatalities because they affect a large group of mine employees when they occur; for example, 33% of the fatalities in 2016 were a result of falls of ground (Slater, 2017).

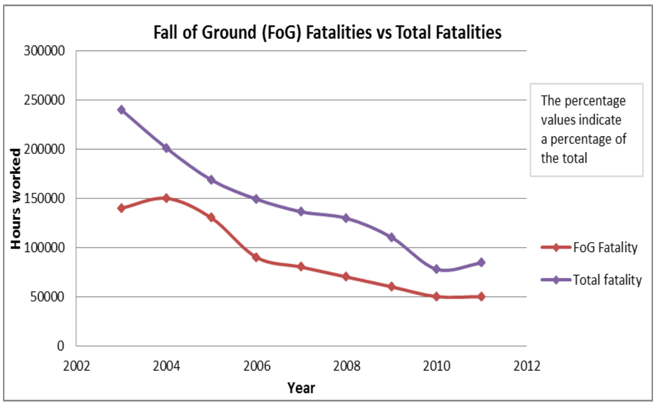

Figure 1. Fall of ground fatalities per million hours worked (DMR 2010)

These are typically caused by improper support of the hangingwall as illustrated in Figure 2, an illustration of typical support in longwall mining.

To mitigate the risk of rock falls, the hangingwall is supported using support packs. It is believed that because a support pack can be of dimensions up to 2 metres in diameter, it supports a larger area and offers more support strength (up to 10,000 kN or 1000 tons) than a typical mine prop or pole in longwall mining with wide tunnels. It is therefore more appropriate to utilize support packs to support the hangingwall in such instances. Large unsupported rock masses require much more support from the mechanism used, hence the need for cementitious grout packs. Using support packs enables a mine to maximise the spacing of support mechanisms in an area in terms of the number of supports required.

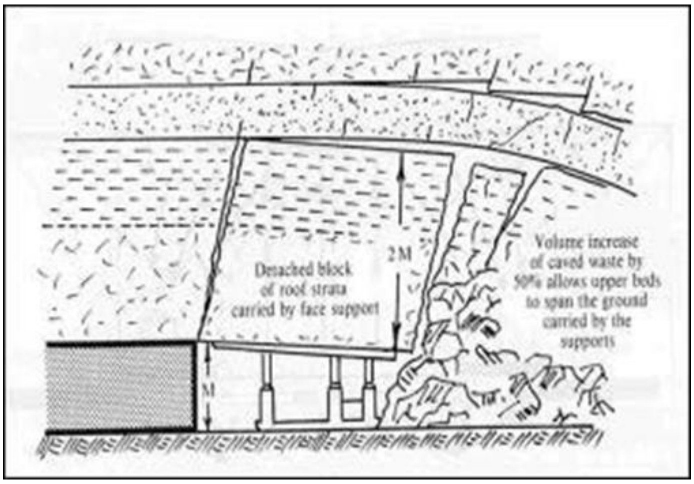

Figure 2. A depiction of an improperly supported mine roof indicating detachment (Mining and Geomorphology, 2017).

The cementitious grout support pack used in the hard rock mining industry is a cement-based formulation that creates support for the heavy hangingwall. The strength of the cement-based pack depends on the length of the curing process. Cementitious grout packs are typically cured for a period of 7 to 28 days. The effect of curing time is illustrated by the examples of results of compressive strength tests for different cementitious pack-curing times as set out and compared in Table 1.

Table 1. Summary of results for different curing times

| Company | Curing time (days) | Average force (kN) | Displacement (mm) |
|---|---|---|---|
| A | 7 | 2418 | 400 |
| B | 7 | 3162 | 400 |
| A | 21 | 2434 | 400 |
| B | 21 | 3587 | 400 |
| SPM3 | 14 | 7091 | 400 |
| SPM4 | 14 | 6183 | 400 |

Some mine suppliers have come up with special design parameters to achieve the required composition for the desired properties (Batchler 2017) and good value propositions. For example, Company A uses round configuration packs while Company B uses square configurations of different sizes. In surface mining, the backfill used is a mixture of tailings from excavations mixed with water. These materials can carry uniformly distributed compressive loads of up to 3,000 kN (300 tons).

The majority of the backfill materials, which are made up of quartzite tailings and excavated rock fragments, are readily available as they are a by-product of mining activities. Most suppliers add the cement to the backfill to strengthen it and although cement is expensive compared to mine tailings, it is generally used to harden the material only and is readily available (Van Heerden 2007). The downside is that the risks associated with cement are introduced to mine employees when it disintegrates and releases dust that may contain crystalline silica (CS) (Lafarge, 2011).

The geotextile bag in which the cementitious grout packs are contained is typically a woven plastic bag that may break open as the pack is slowly compressed by the heavy hangingwall over time. This is influenced by the weight of the rock mass supported by the pack and the spacing of the packs amongst others. Should the geotextile bag break open, dust particles will be slowly and consistently released into the environment/atmosphere in which mine employees work and carried throughout the mine by the mine’s ventilation systems.

The difference in strength of the cement pack and tailings is how they yield over time. A solid pack of cement will disintegrate suddenly when its strength is quickly surpassed i.e. no yielding will be experienced by the pack when impact loads are experienced, while a softer pack will yield and disintegrate gradually. Regardless of the manner in which the different support packs disintegrate under severe loading conditions, gradual loading over a long time may also lead to cement based support packs releasing some dust particles into the atmosphere in which mine employees work.

Cementitious grout support packs that have cured for a specified number of days are subjected to a standardised test method to assess the various strength characteristics of various curing times per pack. The pack is subjected to a gradually increasing compressive load that simulates the loading environment until the pack fails completely. The load and displacement at which failure occurs is reported to the supplier. Prior to the complete failure, the cementitious grout support pack will start to crumble or show localised disintegration.

In the mining environment, the cementitious grout pack disintegration occurs gradually under increased hangingwall weight as the wall moves down against the support pack. The bag will start to deform and tear as the pack yields under load, the hangingwall will then be supported by the residual support strength. Dust particles could escape through the gaps in the geotextile bag and may be spread by the mine’s ventilation systems. The dust that is released into the mine’s atmosphere prior to the complete failure of a cementitious grout pack is the focus of this paper.

In general, it is assumed that bulk material has a particle size distribution (PSD) that is large enough not to pose a threat to human health. However, a small fraction of the material may be fine enough to have the potential of being inhaled when made airborne and reaching the alveoli of the lung.

Internationally, producers of minerals are required to label and classify their mineral products in accordance with the United Nation's (UN) Globally Harmonised System (GHS) of Classification and Labelling of Chemicals. The European Regulation on the Classification, Labelling and Packaging (CLP) of substances and mixtures has been aligned to the GHS. The requirement is that industrial mineral producers assess the health effects of the fine fraction of Crystalline Silica (CS) and follow the requirements for classification. The fine fraction of CS is classified as a STOT RE Category 1, which stands for "specific target organ toxicity repeated exposure" and "Category 1" refers to silicosis as the hazard. A mineral mixture that contains more than 1 wt% fine fraction CS has to have a hazard classification. STOT RE 1 is for a product with ≥ 10 wt% fine fraction CS and STOT RE 2 for a product with 1 – 10 wt% fine fraction CS.

The fine fraction CS is a problem to employees and users of the products only once the bulk material becomes airborne. The Metrology Working Group of the Industrial Minerals Association in Europe (IMA-EU) has developed the Size-Weighted Potential Respirable Fraction (SWeRF) and SWeRF crystalline silica (SWeRFcs) methods respectively (IMA-Europe 2012). These methods are used to quantify the fine fraction of CS in a bulk material that has the potential to enter the gas exchange regions of the lung when the bulk material becomes airborne. In other words, SWeRF explains the relationship between the PSD of the bulk material and the probability of the particles reaching the alveoli according to the European Standard EN 481 (European Committee For Standardization 1993), which describes how the particles behave when the bulk material is made airborne.

The SWeRF method has been used to establish the potential respirable fraction of the bulk material for classification and labelling purposes. This method is only one method that may be employed as part of a risk assessment and does not aim to replace conventional exposure measurements (Pensis et al. 2013).

In the pilot study, the SWeRF method was used to determine the fine fraction of the bulk cementitious support pack material (SPM) to establish the fine fraction of CS. This paper explores possible risks introduced to mine employees when the cementitious grout support pack disintegrates.

## 3 OBJECTIVE

The objective of the pilot study was to assess the probable risk that mine employees may be exposed to respirable crystalline silica (RCS) contained in SPM.

## 4 METHODOLOGY

For the purpose of this paper, the focus was on the fine dust that may be generated as the pack disintegrates. Bulk samples of the SPM were used in this study:

- SPM1 – block of cementitious grout support pack material that was crushed to smaller grains in the laboratory (Mine 1);
- SPM2 – dry, milled, bulk product (Mine 2);
- SPM3 – finer material of support pack from Supplier 1 (after mechanical testing); and
- SPM4 – finer material of support pack from Supplier 2 (after mechanical testing).

Some of the material was supplied in lumps and was manually crushed with a hammer into workable grains.

Qualitative X-Ray Diffraction (XRD) was used to determine the CS percentage in the bulk samples. The samples were sieved through a 1 mm screen and analysed as is and no sample preparation was carried out that could affect the composition of the sample or the PSD.

Particle Size Analysis (PSA) using laser light scattering was carried out on the bulk and the fine fraction samples to determine the PSD.

The SWeRF method developed by IMA-EU (Pensis et al. 2013) contains the details of the method and only a brief summary is provided for the benefit of the reader. There are two approaches in SWeRF:

- Calculation of the fine fraction from the PSA (i.e. SWeRF*calc*): the PSD from the laser light scattering method is used in the formula provided. The SWeRF*calc* method is useful when a bulk material has a uniform composition.

$$\mathrm{SWeRF} = \int_{D=0}^{D=\infty} P(D) \times R(D)\,\mathrm{d}D \tag{1}$$

where P(D) is the particle size distribution for aerodynamic diameter D; R(D) the probability that particles of aerodynamic diameter D may reach the gas exchange region, according to EN 481; and D is the aerodynamic diameter = d × √(SG), where SG is the specific gravity.

- The SWeRF sedimentation method (SWeRF*sed*): a known amount of the bulk material was suspended in a liquid medium (e.g. water), thoroughly mixed and then allowed to settle. The larger, heavier particles settled much faster than the fine fraction of the material. After a pre-determined time, the suspension that contains the fine fraction was extracted, dried and weighed. The percentage of fine fraction in the bulk material was determined by weighing the dried suspension that contained the fine fraction. The CS concentration was determined using qualitative XRD.

$$\text{SWeRF}(\%) = \frac{H}{h} \times \frac{m}{M} \times 100 \qquad (2)$$

where H is the height of the total column of fluid that is used for sedimentation, h the height to which the suspended fine fraction is extracted at the calculated time, M the total mass that was dispersed, and m is the mass of the residue in the extracted supernatant.

The SWeRF*sed* method is useful when a bulk material does not have a homogenous composition or when the CS has a greater density than the rest of the material; i.e. when the bulk material is made airborne, the distribution of dust will not be homogenous.

## 5 RESULTS AND DISCUSSION

### 5.1 *Qualitative XRD analysis*

The estimated crystalline silica (CS) percentages of the bulk materials are summarised in Table 2.

Table 2. Estimated crystalline silica concentration (%) in the bulk material

| Sample | CS wt% |
|---|---|
| SPM1 | ± 3.0 |
| SPM2 | ± 3.2 |
| SPM3 | ± 2.1 |
| SPM4 | ± 1.2 |

The percentages of silica in the bulk material are equal to and below 3.2%.

### 5.2 *Particle Size Analysis (PSA) of the bulk material*

A summary of the PSD is provided in Table 3. The D50 is the median particle size; D10 is the particle size (in micron) where 10% of the sample has a size distribution that is smaller than the D10 size [for example, for SPM1, 10% of the PSD is smaller than 9.4 micron] and D90 is where 90% of the sample has a size distribution that is smaller than the D90 size. $PM_{10}$ is the estimated percentage of the sample with a particle size of below 10 micron.

Table 3. Particle size distribution of the bulk material

| Sample | D10 (µm) | D50 (µm) | D90 (µm) | $PM_{10}$ (%) |
|---|---|---|---|---|
| SPM1 | 9.4 | 28.3 | 98.8 | 11.9 |
| SPM2 | 6.0 | 15.6 | 57.7 | 27.6 |
| SPM3 | 11.7 | 31.0 | 114.4 | 6.5 |
| SPM4 | 13.1 | 42.9 | 102.1 | 5.7 |

For SPM1 and SPM2 a substantial fraction of the bulk material is made up of particles of below 10 µm; the $PM_{10}$ concentrations are 11.9% and 27.6% respectively.

### 5.3 *SWeRF by calculation (SWeRFcalc)*

The SWeRF formula (1) was used to calculate the fine fraction from the PSD and the results are summarised in Table 4.

Table 4. SWeRF by calculation using particle size distribution

| Sample | Density (g/cm$^3$) | SWeRF *calc* Wt% |
|---|---|---|
| SPM1 | 2.39 | 0.3 |
| SPM2 | 2.21 | 2.5 |
| SPM3 | 2.80 | 0.1 |
| SPM4 | 3.10 | 0.2 |

According to the SWeRF calculation, only one sample, SPM2, has a fine fraction (at 2.5%) that may be of concern according to the EN481 definition. The other SPM samples have fine fractions of below 1 wt%.

### 5.4 *SWeRF by sedimentation (SWeRFsed)*

If the sample is homogenous, the sedimentation SWeRF should give similar results to the calculated SWeRF. Table 5 summarises the fine fraction that was measured using the SWeRF*sed* method. The estimated CS concentration in the SWeRF sample (i.e. SWeRF*cs*) was determined using XRD.

Table 5. Estimated crystalline silica concentration in the fine fraction as measured by the SWeRF*sed* method

| Sample | SWeRF*sed* Wt% | SWeRF*cs* Wt% |
|---|---|---|
| SPM1 | 0.5 | 6.1 |
| SPM2 | 0.2 | 2.5 |
| SPM3 | 1.3 | 41.9 |
| SPM4 | 0.3 | 14.0 |

The SWeRF*sed* method shows that between 0.2% and 1.3% of the bulk material consists of fine particles. More importantly, the fine fraction that was isolated using the SWeRF*sed* method contains between 6.1% and 41.9% CS.

The calculated SWeRF compared well with the sedimentation SWeRF for SPM1 and SPM4. However, a significant difference is found between the SWeRF*calc* and the SWeRF*sed* results for SPM2 and SPM3, which could be as a result of the CS having a higher density than the rest of the material or that the sample is not homogenous (Pensis et al. 2013).

### 5.5 *Particle Size Analysis (PSA) of the fine fraction*

PSA was carried out to determine if the fine fraction that was isolated using the SWeRF*sed* method was within the respirable range. Table 6 summarises the PSD of the SWeRF*sed* material.

Table 6. Particle size distribution of the SWeRF*sed* material

| Sample | D10 (µm) | D50 (µm) | D90 (µm) | $PM_{10}$ (%) |
|---|---|---|---|---|
| SPM1 | 0.6 | 1.4 | 5.0 | 93.3 |
| SPM2 | 1.2 | 2.1 | 34.0 | 80.6 |
| SPM3 | 0.2 | 3.5 | 9.5 | 91.5 |
| SPM4 | 0.3 | 5.0 | 10.5 | 88.9 |

The PSA confirms that the SWeRF*sed* fraction had a median size range of below 5 µm. Although 80.6% of SPM2 was below 10 micron, there was still a small portion of the sample with a size distribution above 10 µm (D90 of 34 µm) – the sample may have required a longer sedimentation time owing to the nature of the particles.

## 6 CONCLUSION

Four SPM samples were assessed to determine the amount of CS that occurs in the fine fraction of the bulk material.

The bulk material contained a small fraction of fine particles (< 2.5%) that, when made airborne, had a 97.3% probability of entering the gas exchange regions of the lungs of mine employees (in the absence of personal protective equipment), according to the EN 481 definition.

The bulk material as submitted contained CS percentages of below 3.2%. However, the fine fraction that was isolated using the SWeRF*sed* method contained CS concentrations of between 2.5% and 41.9%. If the bulk material were to be classified in accordance with the GHS, then all the bulk samples would have to have a hazard classification because the CS concentration in the fine fraction is more than 1 wt%.

It should be noted that the time period before these packs start disintegrating, causing dust to become airborne, depends on factors such as the quality of the pack and the conditions that the pack is subjected to. The slow release of dust over time will be investigated further by the CSIR.

This pilot study illustrates the need to investigate the material that is used in cementitious grout support packs. A thorough risk assessment is required from a workplace exposure perspective, especially since waste material combined with cement may be a preferred choice for the majority of support pack manufacturers.

## 7 RECOMMENDATIONS AND WAY FORWARD

The SWeRF method has proven useful in the isolation of the fine fraction in bulk material from the mining industry. This method may be applied to other types of bulk material, such as material from waste dumps, tailings and processing, and for the general characterisation of ore.

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