In-Depth Survey Report

Concrete Surface Preparation Tools Machine 1

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DEPARTMENT OF HEALTH AND HUMAN SERVICES
Centers for Disease Control and Prevention
National Institute for Occupational Safety and Health

Site Surveyed:

Operative Plasterers' and Cement Masons' International Association Training Center
New Brighton, MN

NAICS Code:

238340 Tile and Terrazzo Contractors
238110 Structure Contractors

Survey Dates:

March 25, 2014

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Table of Contents

Abstract

Workplace exposure to respirable crystalline silica can cause silicosis, a progressive lung disease marked by scarring and thickening of the lung tissue. Quartz is the most common form of crystalline silica. Crystalline silica is found in several construction materials, such as brick, block, mortar and concrete. Construction tasks that cut, break, grind, abrade, or drill those materials have been associated with overexposure to dust containing respirable crystalline silica. Colored, stained, and polished concrete floors are increasingly popular for use in homes, offices, retail establishments, schools, and other commercial and industrial settings. Some businesses specify integrally-colored concrete floors in new stores in place of vinyl composite tile. Polished concrete floors are durable, sanitary, and easy to maintain. NIOSH scientists are conducting a study to develop and evaluate engineering control recommendations for respirable crystalline silica from concrete polishing operations. This survey was part of that study.

NIOSH staff visited the Operative Plasterers' and Cement Masons' International Association (OPCMIA) facility in New Brighton, MN from March 25 - 26, 2014. During the site visit, personal breathing zone air samples were collected to measure the respirable dust and respirable crystalline silica exposures of the operator while he used a concrete polisher (Prep-Master 2420, Substrate Technology, Inc., Morris, IL). Additionally, area samples were collected on top of the machine and at four locations around it during the polishing task.

The Prep-Master 2420 floor polisher was outfitted with a local exhaust ventilation system consisting of two exhaust ports located on the back of the shroud that encased 12 polishing tools. The exhaust from both ports was connected to a vacuum system rated at approximately 10194 liters per minute (L/min) (360 cubic feet per minute (cfm)) of suction. The vacuum was equipped with a pre-separator. Once through the pre-separator, the air stream was High Efficiency Particulate Air (HEPA) filtered and then recirculated to the room.

The aim of this survey was to collect emissions data from the concrete polisher using different grits while operating the dust collection system provided with the machine. Sample times varied based on the length of time needed to polish a rectangular area of 20 square-meters (m^2) (216 square-feet (ft^2)) with a given grit and ranged between 24 to 49 minutes with an average sample time of 31.8 minutes.

Overall, the air samples ranged from 23 to 38% quartz. The mean quartz percentage for all of the air samples was 28.5%. A bulk sample was collected from the dust captured in the bag filter of the vacuum system connected to the concrete polisher; it contained 45% quartz. No cristobalite or tridymite were detected in the bulk sample. Therefore, for the purposes of this report the terms respirable crystalline silica or respirable quartz may be used interchangeably.

If exposures were to continue throughout the entire workday and assuming steady, constant, and similar dust generation rates as those measured during this survey, personal breathing zone quartz concentrations using the Prep-Master 2420 concrete polisher fitted with the vacuum dust collection system described above would have ranged from 5 to 63 times the NIOSH Recommended Exposure Limit (REL) for respirable quartz of 50 micrograms per cubic meter ($\mu g/m^3$) as a time weighted average, depending on the grit selected.

The metal bond grits produced about 25% less respirable dust and respirable quartz than the resin bond grits when the personal operator's breathing zone samples were compared. The air sampling results were similar between the two metal bond grits used in this survey. However, when the operator switched from the metal to the resin bond grits (samples collected when using Resin 3), a large amount of respirable dust and respirable quartz was measured in the sample results. Once the floor space was polished with Resin 3, the remaining resin bonds (Resins 4, 5, and 6) did not generate as much respirable dust or respirable quartz as Resin 3, but still generated more than twice the amount of dust measured when using the initial metal bond grits.

The Prep-Master 2420 concrete polisher evaluated in this survey was equipped with a local exhaust ventilation system intended to control and remove dust particles generated during the concrete polishing process. However, the dust control system needs modifications so that worker exposure to respirable crystalline silica can be reduced during concrete finishing operations.

Introduction

Background for Control Technology Studies

The National Institute for Occupational Safety and Health (NIOSH) is the primary Federal agency engaged in occupational safety and health research. Located in the Department of Health and Human Services, it was established by the Occupational Safety and Health Act of 1970. This legislation mandated NIOSH to conduct a number of research and education programs separate from the standard setting and enforcement functions carried out by the Occupational Safety and Health Administration (OSHA) in the Department of Labor. An important area of NIOSH research deals with methods for controlling occupational exposure to potential chemical and physical hazards. The Engineering and Physical Hazards Branch (EPHB) of the Division of Applied Research and Technology has been given the lead within NIOSH to study the engineering aspects of health hazard prevention and control.

Since 1976, EPHB has conducted a number of assessments of health hazard control technologies on the basis of industry, common industrial process, or specific control techniques. Examples of these completed studies include the foundry industry; various chemical manufacturing or processing operations; spray painting; and the recirculation of exhaust air. The objective of each of these studies has been to document and evaluate effective control techniques for potential health hazards in the industry or process of interest, and to create a more general awareness of the need for or availability of an effective system of hazard control measures.

These studies involve a number of steps or phases. Initially, a series of walk-through surveys is conducted to select plants or processes with effective and potentially transferable control concept techniques. Next, in-depth surveys are conducted to determine both the control parameters and the effectiveness of these controls. The reports from these in-depth surveys are then used as a basis for preparing technical reports and journal articles on effective hazard control measures. Ultimately, the information from these research activities builds the data base of publicly available information on hazard control techniques for use by health professionals who are responsible for preventing occupational illness and injury.

Background for this Study

Crystalline silica refers to a group of minerals composed of silicon and oxygen; a crystalline structure is one in which the atoms are arranged in a repeating three-dimensional pattern [Bureau of Mines 1992]. The three major forms of crystalline silica are quartz, cristobalite, and tridymite; quartz is the most common form [Bureau of Mines 1992]. Respirable crystalline silica refers to that portion of airborne crystalline silica dust that is capable of entering the gas-exchange regions of the lungs if inhaled; this includes particles with aerodynamic diameters less than approximately 10 micrometers (μm) [NIOSH 2002]. Silicosis, a fibrotic disease of the lungs, is an occupational respiratory disease caused by the inhalation and deposition of respirable crystalline silica dust [NIOSH 1986]. Silicosis is irreversible, often progressive (even after exposure has ceased), and potentially fatal. Because no effective treatment exists for silicosis, prevention through exposure control is essential.

Crystalline silica is a constituent of several materials commonly used in construction, including brick, block, and concrete. Many construction tasks have been associated with overexposure to dust containing crystalline silica [Chisholm 1999, Flanagan et al. 2003, Rappaport et al. 2003, Woskie et al. 2002]. Among these tasks are tuckpointing, concrete cutting, concrete grinding, abrasive blasting, and road milling [Nash and Williams 2000, Thorpe et al. 1999, Akbar-Khanzadeh and Brillhart 2002, Glindmeyer and Hammad 1988, Linch 2002, Rappaport et al. 2003]. Colored, stained, and polished concrete floors are increasingly popular for use in homes, offices, retail establishments, schools, and other commercial and industrial settings. For example, some a major chain store has specified integrally-colored concrete floors in its new stores in place of vinyl composite tile. Polished concrete floors are durable, sanitary, and easy to maintain (Figure 1).

Figure 1: A polished concrete floor (Courtesy of the Concrete Polishing Association)

Concrete floor finishing work is performed by employees of tile and terrazzo contractors (NAICS 238340) and poured concrete foundation and structure contractors (NAICS 238110). In 2007, there were 11,180 tile and terrazzo contracting firms and 24,303 poured concrete contractors in the United States, employing nearly 312,000 construction workers [Census 2012]. The Bureau of Labor Statistics [2012] reported that there were 206,600 cement masons, concrete finishers, and terrazzo workers (SOC 47-2050) employed in 2008. Only about 5 percent of cement masons, concrete finishers, segmental pavers, and terrazzo workers were self-employed, a smaller proportion than in other building trades. Most self-employed masons specialize in small jobs, such as driveways, sidewalks, and patios [BLS 2012]. The number of cement masons, concrete finishers, and terrazzo workers is projected to be 234,500 in 2018 [BLS 2009]. The increasing number of workers and the growing popularity of concrete as a flooring material will only add to the number of workers exposed to silica from the tasks involved in their construction. Sentinel Event Notification System for Occupational Risk (SENSOR) surveillance data from Michigan, New Jersey, and Ohio identified 7 cases of silicosis in concrete and terrazzo finishers from 1993-2002 [NIOSH 2007]. The success of this study will reduce the number of cases of silicosis among the growing ranks of these workers.

Many walk-behind concrete surfacing tools are sold by the manufacturers with dust controls as original equipment (Figure 2). Other dust controls are offered as after-market options. However, there is little research available that demonstrates that either the original equipment or after-market controls are effective in limiting worker exposures to respirable dust or respirable crystalline silica. Flanagan et al. [2003] reported that seven of nine samples collected during concrete floor sanding exceeded the ACGIH® TLV® for respirable quartz (at that time 0.05 mg/m^3, identical to the 10-TWA NIOSH REL). The geometric mean and geometric standard deviation for those nine quartz samples were 0.07 mg/m^3 and 2.62 mg/m^3, respectively. These exposures demonstrate the need to identify effective dust controls for walk-behind concrete surfacing tools to reduce silica exposures among workers using these tools.

EPHB researchers have been unable to identify a recently-published study of the effectiveness of those local exhaust ventilation (LEV) systems. The lack of data demonstrating the effectiveness of dust controls and the increasing popularity of polished concrete floors prompted our partners (the equipment manufacturers and the union that represents the users of these tools and dust controls) to request that NIOSH examine the efficacy of the dust controls used with walk-behind concrete surface preparation equipment.

Research methods are readily available to conduct a study of dust control effectiveness for these tools. Examples include a study by Hallin [1983] and BG Bau [2006]. Working in Sweden, Hallin examined the performance of dust controls for percussion drills, drill hammers, ceiling, floor, and wall grinders, scaling machines, floor-milling machines, and concrete channel-cutting machines. The tests were conducted in a 5x6x2.4 meter room erected inside a large factory. Personal breathing zone (PBZ) and area samples for respirable dust and quartz were collected while a laborer operated the equipment with and without the dust controls, and with and without ventilation to the room. Hallin tested 10 floor grinding machines. PBZ quartz results ranged from 0.08 mg/m^3 to 0.24 mg/m^3 for tools used with dust controls.

In a series of experiments in Bavaria, BG Bau [2006] examined dust emissions from hand-held tools such as wall chasers, diamond cutters and drill hammers operated in a 6.9x6.7x4.3 meter test room at a worker training center (Bavarian BauAkademie). Tests were conducted with the dust controls operating while the tools were used by a skilled operator. The test room was unventilated during the tests and the operator wore appropriate respiratory protection. PBZ and area samples of inhalable and respirable dust were collected during the tests. Video exposure monitoring was performed for distribution to the tool manufacturers to generate ideas to improve the dust collection systems.

The long-term objective of this current study is to provide practical recommendations for effective dust controls that will prevent overexposures to respirable crystalline silica during concrete finishing operations. The specific aims of the project: 1) To evaluate the effectiveness of the LEV and dust suppression (water) systems sold for use with walk-behind scarifiers, grinders, and polishers and offer research-based recommendations to improve them if necessary; 2) To establish a partnership with manufacturers and users of walk-behind concrete surface preparation equipment; 3) To establish a standard method for evaluating dust controls for tools used in construction in the United States; and 4) To bridge the gap between the pool of available knowledge and the lack of standards and regulations for dust controls in construction and disseminate the information in the form of technical reports, journal articles, NIOSH Workplace Solutions documents, and trade journal articles.

In 2012, the Association of Equipment Manufacturers (AEM) approached EPHB to request an evaluation of the exposures and controls associated with walk-behind tools used in concrete grinding and polishing operations. The Operative Plasterers' and Cement Masons' International Association (OPCMIA) contacted EPHB with the same concerns. These organizations recognized EPHB's expertise and experience in construction engineering control research. The AEM is a long-time partner of NIOSH/DART, participating in the asphalt paving and milling studies, among others. The fact that both the manufacturers and users of the tools are invested in this project from its conception increases the likelihood of success and that any resulting recommendations will be implemented.

Site and Process Description

Introduction

The Cement Masons, Plasterers and Shophands Joint Apprenticeship Training Committee (JATC), Local 633 training center is a state-of-the-art, 20,000 square-feet (ft^2) structure. Local 633 is equipped with several classrooms, a lunchroom, office space and over 15,000 ft^2 of hands-on instruction workspace. Fully equipped and staffed to conduct 3 classes simultaneously with as many as 30 students in each class, OPCMIA offers Union members training at both the apprenticeship and journey levels. OSHA-30 and many other certification courses are also integrated into the curriculum. The facility is located in New Brighton, Minnesota.

Process Description

A polished concrete floor has a glossy, mirror-like finish. The design options for polished concrete are extensive with nearly any color option, patterns created with saw cuts, and aggregates or other interesting objects embedded into the concrete prior to polishing. The reflectivity of the floor can also be controlled by using different levels of polishing.

Heavy-duty polishing machines equipped with progressively finer grits of diamond-impregnated segments or disks (similar to sandpaper) are used to gradually grind down surfaces to the desired degree of shine and smoothness. The polishing process begins with the use of coarse diamond segments bonded in a metallic matrix. These segments are coarse enough to remove minor pits, blemishes, stains, or light coatings from the floor in preparation for final smoothing. Depending on the condition of the concrete, this initial rough grinding is generally a three- to four-step process.

The next steps involve fine grinding of the concrete surface using diamond abrasives embedded in a plastic or resin matrix. Some polishing specialists use even finer grits of polishing disks (a process called lapping) until the floor has the desired sheen. For an extremely high-gloss finish, a final grit of 1500 or finer may be used. Experienced polishing personnel know when to switch to the next-finer grit by observing the floor surface and the amount of material being removed.

During the polishing process an internal impregnating sealer is applied. The sealer sinks into the concrete and is invisible to the naked eye. It not only protects the concrete from the inside out, it also hardens and densifies the concrete. Some polishing specialists apply a commercial polishing compound onto the surface during the final polishing step, to increase the sheen. These compounds also help clean any residue remaining on the surface from the polishing process and leave a dirt-resistant finish.

In simple steps, the concrete polishing process can be summarized as follows:

- Remove existing coatings (for thick coatings, use a 16- or 20-grit diamond abrasive or more aggressive tool specifically for coating removal).
- Seal cracks and joints with an epoxy or other semi-rigid filler.
- Grind with a 30- or 40-grit metal-bonded diamond.
- Grind with an 80-grit metal-bonded diamond.
- Grind with a 150-grit metal-bonded diamond (or finer, if desired).
- Apply a chemical hardener to densify the concrete.
- Polish with a 100- or 200-grit resin-bond diamond, or a combination of the two.

- Polish with a 400-grit resin-bond diamond.
- Polish with an 800-grit resin-bond diamond.
- Finish with a 1500- or 3000-grit resin-bond diamond (depending on the desired sheen level).
- Optional: Apply a stain guard to help protect the polished surface and make it easier to maintain.

Concrete polishing can be completed using wet or dry methods. Although each has its advantages, dry polishing is the method most commonly used in today's industry because it is faster, more convenient, and environmentally friendly. Wet polishing methods use water to cool the diamond abrasives and eliminate grinding dust. Because the water reduces friction and acts as a lubricant, it increases the life of the polishing abrasives. The main disadvantage of the wet method is the cleanup. Wet polishing creates a slurry that must be collected and disposed of in an environmentally friendly manner. With dry polishing, no water is required. Instead, the floor polisher is connected to a dust-removal system that, in theory, vacuums most of the generated dust from the polishing process.

Many polishing specialists use a combination of both, the wet and dry polishing methods. Typically, dry polishing is used for the initial grinding steps, when a larger amount of concrete is to be removed. As the surface becomes smoother, and the coarser metal-bonded abrasives are switched to the finer resin-bonded diamond abrasives, the crew generally changes to wet polishing methods.

Occupational Exposure Limits and Health Effects

As a guide to the evaluation of the hazards posed by workplace exposures, NIOSH investigators use mandatory and recommended Occupational Exposure Limits (OELs) when evaluating chemical, physical, and biological agents in the workplace. Generally, OELs suggest levels of exposure to which most workers may be exposed up to 10 hours per day, 40 hours per week for a working lifetime without experiencing adverse health effects. It is, however, important to note that not all workers will be protected from adverse health effects even though their exposures are maintained below these levels. A small percentage may experience adverse health effects because of individual susceptibility, a pre-existing medical condition, and/or hypersensitivity (allergy). In addition, some hazardous substances may act in combination with other workplace exposures, the general environment, or with medications or personal habits of the worker to produce health effects even if the occupational exposures are controlled at the level set by the exposure limit. Combined effects are often not considered in the OEL. Also, some substances are absorbed by direct contact with the skin and mucous membranes, and thus can increase the overall exposure. Finally, OELs may change over the years as new information on the toxic effects of an agent become available.

Most OELs are expressed as a TWA exposure. A TWA exposure refers to the average airborne concentration of a substance during a normal 8- to 10-hour workday. Some substances have a recommended Short Term Exposure Limit (STEL) or ceiling values which are intended to supplement the TWA where there are recognized toxic effects from higher exposures over the short-term.

In the U.S., OELs have been established by Federal agencies, professional organizations, state and local governments, and other entities. The U.S. Department of Labor OSHA Permissible Exposure Limits (PELs) [29 CFR 1910.1000 2003a] are occupational exposure limits that are legally enforceable in covered workplaces under the Occupational Safety and Health Act. NIOSH recommendations are based on a critical review of the scientific and technical information available on the prevalence of health effects, the existence of safety and health risks, and the adequacy of methods to identify and control hazards [NIOSH 1992]. They have been developed using a weight of evidence approach and formal peer review process. Other OELs that are commonly used and cited in the U.S. include the Threshold Limit Values (TLVs®) recommended by American Conference of Governmental Industrial Hygienists (ACGIH®), a professional organization [ACGIH 2013]. ACGIH® TLVs are considered voluntary guidelines for use by industrial hygienists and others trained in this discipline “to assist in the control of health hazards.” Workplace Environmental Exposure Levels® (WEELs) are recommended OELs developed by the American Industrial Hygiene Association® (AIHA), another professional organization. WEELs have been established for some chemicals “when no other legal or authoritative limits exist” [AIHA 2007].

OSHA requires an employer to furnish employees a place of employment that is free from recognized hazards that are causing or are likely to cause death or serious physical harm [Occupational Safety and Health Act of 1970, Public Law 91–596, sec. 5(a)(1)]. Thus, employers are required to comply with OSHA PELs. Some hazardous agents do not have PELs, however, and for others, the PELs do not reflect the most current health-based information. Thus, NIOSH investigators encourage employers to consider the other OELs in making risk assessment and risk management decisions to best protect the health of their employees. NIOSH investigators also encourage the use of the traditional hierarchy of controls approach to eliminating or minimizing identified workplace hazards. This includes, in preferential order, the use of: (1) substitution or elimination of the hazardous agent, (2) engineering controls (e.g., local exhaust ventilation, process enclosure, dilution ventilation) (3) administrative controls (e.g., limiting time of exposure, employee training, work practice changes, medical surveillance), and (4) personal protective equipment (e.g., respiratory protection, gloves, eye protection, hearing protection).

Crystalline Silica Exposure Limits

When dust controls are not used or maintained or proper practices are not followed, respirable crystalline silica exposures can exceed the NIOSH REL, the OSHA PEL, or the ACGIH TLV. NIOSH recommends an exposure limit for respirable crystalline silica of 0.05 mg/m^3 as a TWA determined during a full-shift sample for up to a 10-hr workday during a 40-hr workweek to reduce the risk of developing silicosis, lung cancer, and other adverse health effects [NIOSH 2002]. When source controls cannot keep exposures below the NIOSH REL, NIOSH also recommends minimizing the risk of illness that remains for workers exposed at the REL by substituting less hazardous materials for crystalline silica when feasible, by using appropriate respiratory protection, and by making medical examinations available to exposed workers [NIOSH 2002]. In cases of simultaneous exposure to more than one form of crystalline silica, the concentration of free silica in air can be expressed as micrograms of free silica per cubic meter of air sampled (µg/m^3) [NIOSH 1975].

$$\mu g\, SiO_2/m^3 = \frac{\mu g\, Q + \mu g\, C + \mu g\, T + \mu g\, P}{V} \qquad (1)$$

Where Q is quartz, C is cristobalite, and T is tridymite, P is “other polymorphs”, and V is sampled air volume.

The current OSHA PEL for respirable dust containing crystalline silica for the construction industry is measured by impinger sampling. In the construction industry, the PELs for cristobalite and quartz are the same. The PELs are expressed in millions of particles per cubic foot (mppcf) and calculated using the following formula [29 CFR 1926.55 2003b]:

$$\text{Respirable PEL} = \frac{250\ \text{mppcf}}{\%\ \text{Silica} + 5} \qquad (2)$$

Since the PELs were adopted, the impinger sampling method has been rendered obsolete by gravimetric sampling [OSHA 1996]. OSHA currently instructs its compliance officers to apply a conversion factor of 0.1 mg/m3 per mppcf when converting between gravimetric sampling and the particle count standard when characterizing construction operation exposures [OSHA 2008]. On September 12, 2013, OSHA published a Notice of Proposed Rulemaking (NPRM) for occupational exposure to respirable crystalline silica. The NPRM was published in the Federal Register and proposes a PEL of 0.050 mg/m^3 for respirable crystalline silica as an 8-hr TWA exposure [78 Fed. Reg. 56274 (2013)].

The ACGIH TLV for α-quartz (the most abundant toxic form of silica, stable below 573°C) and cristobalite (respirable fraction) is 0.025 mg/m^3 [ACGIH 2013]. The TLV is intended to mitigate the risk of pulmonary fibrosis and lung cancer.

Methodology

Sampling Strategy

PBZ air samples were collected on the concrete polishing machine operator while multiple polishing grits were used during the site visit. Sampling equipment was also placed on top of the concrete polisher and four area samples were collected on the corners of the polishing space. The polishing area was established as a 7.32 m (24 ft) by 2.74 m (9 ft) (20 m^2 or 216 ft^2) rectangle as shown in Figure 3 below.

Figure 3: Polishing area and area sample array

The evaluated concrete polisher was a Prep-Master 2420 manufactured by Substrate Technology Inc. (STI). The Prep-Master 2420 was connected to a vacuum system that provided local exhaust ventilation to remove the dust generated during the process. Four rotating wheels have provisions to accommodate 12 polishing disks and rotated between 250 and 750 revolutions per minute (rpm). This STI concrete polisher weighs approximately 1000 pounds, and according to the manufacturer's specifications, it is capable of removing 86 square meters (m^2) (925 ft^2) of concrete material per hour [STI 2015]. The physical dimensions of the polisher are 1.90 m L x 0.69 m W x 1.27 m H (75 in L x 27 in W x 50 in H).

Samples were collected while the operator polished the 216 ft^2 area using six different grits, including metal and resin bond. After each run, the polished area was cleaned using a Pulse-Bac 1050H (CDCLarue Industries, Inc., Tulsa, OK) portable vacuum cleaner equipped with high-efficiency particulate air (HEPA) filters.

Figure 4 shows a photo of the grits used during this survey, and they are commonly identified as:

- 30 Metal Bond
- 80 Metal Bond
- 3 Resin Bond
- 4 Resin Bond
- 5 Resin Bond
- 6 Resin Bond

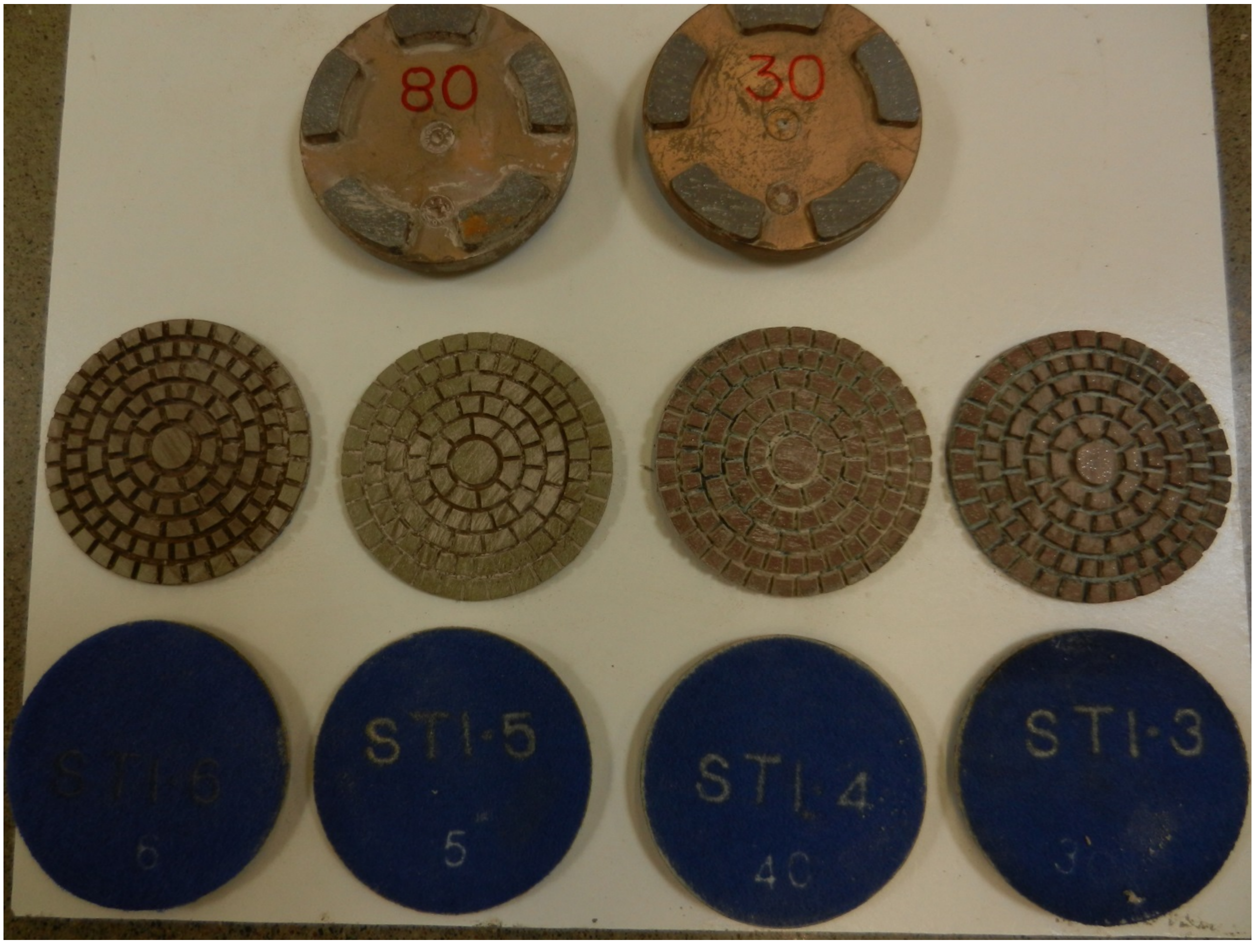

Figure 4: Different Grits used during the survey

Two personal DataRam (pDR, model 1000AN, Thermo Electron Corp., Franklin, MA) mounted on a tripod at breathing zone height (1.5 m) was used to verify that the room was ventilated and cleaned to background respirable dust levels, no greater than 0.05 mg/m^3. Since there are no direct-reading instruments for respirable crystalline silica, using the crystalline silica REL as the respirable dust background level ensures that the background silica concentration will be lower than the NIOSH REL.

Sampling Procedures

Air Sampling

PBZ air samples for respirable particulate and crystalline silica were collected at a flow rate of 10 liters per minute (L/min) with a battery-operated sampling pump (Leland Legacy, SKC, Eighty Four, PA) calibrated before and after each work day using a DryCal Primary Flow Calibrator (Bios Defender 510, Mesa Laboratories, Inc., Lakewood, CO). A sampling pump was clipped to the sampled worker's belt worn at his waist. The pump was connected via Tygon® tubing to a pre-weighed, 47-mm diameter, 5.0-µm pore-size polyvinyl chloride (PVC) filter supported by a backup pad in a three-piece filter cassette sealed with a cellulose shrink band (in accordance with NIOSH Methods 0600 and 7500) [NIOSH 1998, NIOSH 2003]. The front portion of the cassette was removed and the cassette was attached to a respirable dust cyclone (RASCAL, model GK4.162, BGI Inc., Waltham, MA). At a flow rate of 10 L/min, the model GK4.162 cyclone has a 50% cut point (D_{50}) of 4.0 µm [BGI 2011]. D_{50} is the aerodynamic diameter of the particle at which penetration into the cyclone declines to 50% [Vincent 2007]. The cyclone was clipped to the sampled workers' shirts near their breathing zone. In addition to the personal breathing zone sampling equipment was also placed on top of the concrete polisher, and four area samples were collected in the corners of the polishing space. Field blank samples were taken on each sampling day. Bulk dust samples were also collected in accordance with NIOSH Method 7500 [NIOSH 2003].

The target for this study is to evaluate as many tools and grits as possible in the shortest amount of time. Therefore, the high-flow cyclone was specifically developed under this project to provide sample results above the limit of detection (LOD) and above the limit of quantitation (LOQ) for short term samples. It is important to remember that for this industry, workers operate these concrete polishers for a full 8-hour day (and potentially longer) usually only stopping for lunch or to change the tooling and grits on the machines as needed.

The filter samples were analyzed for respirable particulates according to NIOSH Method 0600 [NIOSH 1998]. The filters were allowed to equilibrate for a minimum of two hours before weighing. A static neutralizer was placed in front of the balance (model AT201, Mettler-Toledo, Columbus, OH); each filter was passed over the neutralizer before weighing. The LOD was 20 µg/sample, and the LOQ was 53 µg/sample.

Crystalline silica analysis of filter and bulk samples was performed using X-ray diffraction according to NIOSH Method 7500 [NIOSH 2003]. The LODs for quartz, cristobalite, and tridymite were 5 µg/sample, 5 µg/sample, and 10 µg/sample, respectively. The LOQs for quartz, cristobalite, and tridymite were 17 µg/sample, 33 µg/sample, and 33 µg/sample, respectively.

Control Technology

Many walk-behind concrete surfacing tools are sold with dust controls as original equipment by the manufacturers. Other dust controls are offered as after-market options. However, there is little research available that demonstrates that either the original equipment or after-market controls are effective in limiting worker exposures to respirable dust or respirable crystalline silica. The Prep-Master 2420 floor polisher was outfitted with LEV consisting of two exhaust ports located on the back of the shroud that encased the 12 polishing disks. The exhaust from these ports was connected to a vacuum system with a pre-separator that provided approximately 10194 L/min (360 cfm) of suction, per manufacturers' specification. Once through the pre-separator, the air stream was HEPA filtered and recirculated to the room.

When the concrete polisher was operated, the flow induced by the spinning of the polishing tooling caused a large portion of the dust generated to be collected in the periphery of the shroud, where the vacuum ports were located. Figure 5 shows the dust-collecting shroud and the polishing discs installed on the concrete polisher.

Figure 5: Shroud and polishing disks installed on the Concrete Polisher

Results

The aim of this survey was to collect emissions data from the concrete polisher using different grits while using the dust collection system provided with the machine. This study was also conducted to determine whether the engineering controls employed on this concrete polisher were able to control respirable silica exposures below the NIOSH REL of 50 µg/m^3 (0.05 mg/m^3) if the tasks were to continue throughout an 8-hour day as they would on a regular work-day.

Table 1 includes the sample times, sampling volumes, pump information, grits used per sample, and sample numbers for the samples collected on the operator and on the concrete polisher. Sample times varied based on the length of time needed to polish the 20 m^2 (216 ft^2) rectangle with a given grit, ranging between 24 and 49 minutes with an average sample time of 32 minutes.

Table 1 – General Sample Information

Sample Location	Grit	Sampling Flow Rate (Lpm)	Sample Time (min)	Sample Volume (m^3)	Sample Number
Personal	30 Metal	10.043	49	0.492	PN0311147
Personal	80 Metal	10.043	33	0.331	PN0311446
Personal	3 Resin	10.043	24	0.241	PN0311146
Personal	4 Resin	10.043	31	0.311	PN03111444
Personal	5 Resin	10.043	27	0.271	PN03111445
Personal	6 Resin	10.043	27	0.271	PN03111420
Machine	30 Metal	9.935	49	0.487	PN0311141
Machine	80 Metal	9.935	33	0.328	PN03111410
Machine	3 Resin	9.935	24	0.238	PN03111441
Machine	4 Resin	9.935	31	0.308	PN03111431
Machine	5 Resin	9.935	27	0.268	PN03111437
Machine	6 Resin	9.935	27	0.268	PN03111425

Silica Content in Air and Bulk Samples

Table 2 presents the respirable crystalline silica and respirable dust masses reported for the personal samples and also for those samples located on top of the concrete polisher. The results of the area samples are shown in the Appendix as complementary data for the study. For the operator, the sum of the respirable crystalline silica masses for each of the samples is divided by the sum of the respirable dust masses for those samples and multiplied by 100 to calculate the percent silica over the sample collection time. The total sample collection time was 191 minutes, and the total silica exposure for the operator during this time was about 33%.

Table 2 – Respirable Silica (Quartz) Mass, Respirable Dust Mass, and Percent Silica.

Sample Location	Grit	Sample Number	Respirable Particulate (μg/sample)	Respirable Silica (μg/sample)	% Quartz
Personal	30 Metal	PN0311147	480	120	25.0%
Personal	80 Metal	PN0311446	420	97	23.1%
Personal	3 Resin	PN0311146	2000	760	38.0%
Personal	4 Resin	PN03111444	740	240	32.4%
Personal	5 Resin	PN03111445	530	150	28.3%
Personal	6 Resin	PN03111420	660	190	28.8%
Machine	30 Metal	PN0311141	430	110	25.6%
Machine	80 Metal	PN03111410	370	84	22.7%
Machine	3 Resin	PN03111441	1500	570	38.0%
Machine	4 Resin	PN03111431	490	120	24.5%
Machine	5 Resin	PN03111437	490	150	30.6%
Machine	6 Resin	PN03111425	590	150	25.4%

The percent quartz in each sample was calculated and listed in the last column of Table 2. Overall, the air samples ranged from 23 to 38% quartz. The mean quartz percentage in all of the air samples was 29%. Three blank samples were collected and no crystalline silica was detected on any of the blank samples. A bulk sample was collected from the dust captured in the bag filter of the vacuum system connected to the concrete polisher and it contained 45% quartz. No cristobalite or tridymite were detected in the air samples or bulk sample.

Respirable Crystalline Silica (Quartz) Results

Table 3 includes respirable silica (quartz) concentrations in micrograms per cubic meter (μg/m^3). Table 3 also includes a column listing the current NIOSH REL (same as the OSHA proposed PEL) and indicates whether the collected samples exceeded or not the NIOSH REL. The tables in the Appendix provide the sampling data used to calculate the results provided in Tables 2 and 3.

Table 3 – Respirable Dust and Respirable Crystalline Silica Results

Sample Location	Grit	Sample Time (min)	Respirable Particulate Concentration (μg/m^3)	Respirable Silica Concentration (μg/m^3)	NIOSH Silica REL (μg/m^3)	# over REL*

Personal	30 Metal	49	975	243.85	50	4.9
Personal	80 Metal	33	1267	292.68	50	5.9
Personal	3 Resin	24	8298	3153.11	50	63.1
Personal	4 Resin	31	2377	770.88	50	15.4
Personal	5 Resin	27	1955	553.18	50	11.1
Personal	6 Resin	27	2434	700.69	50	14.0
Machine	30 Metal	49	883	225.96	50	4.5
Machine	80 Metal	33	1129	256.21	50	5.1
Machine	3 Resin	24	6291	2390.54	50	47.8
Machine	4 Resin	31	1591	389.63	50	7.8
Machine	5 Resin	27	1827	559.19	50	11.2
Machine	6 Resin	27	2199	559.19	50	11.2

*Extrapolates the exposure using the evaluated grit as if it had continued for a full shift

**NIOSH Silica REL 50 μg/m^3 (0.05 mg/m^3)

Discussion

If exposures were to continue throughout the entire work-day and assuming steady, constant, and similar dust generation rates as the ones observed during this survey, the LEV used with the Prep-Master 2420 concrete polisher would not be able to protect workers from exposures above the NIOSH REL. With these assumptions in mind, on average, the collected samples with different polishing grits were over 16 times above the NIOSH REL (they ranged from 5 to 63 times greater than the NIOSH REL).

The metal bond grits produced about 25% less respirable dust and respirable silica quartz than the resin bond grits. This seems plausible as the metal bond grits are used for the initial stages of polishing where more material is removed, potentially generating larger particles. The resin bond grits are used for fine polishing and generate more particles in the respirable size range, those capable of entering the operator airways.

The two metal bonds grits used in this survey displayed similar results in terms of particle emissions. However, when switching from the metal to the resin bond (samples collected when using Resin 3), a large amount of respirable dust (8298 μg/m^3) and respirable crystalline silica (3153 μg/m^3) was measured in the sample results. This can be explained by an initial finer polishing over a coarse aggregate on the concrete pad generating finer dust than with the previous metal bonds. Once the floor space was polished with Resin 3, the remaining resin bonds (Resins 4, 5, and 6) did not generate as much respirable dust or respirable crystalline silica as Resin 3. However, the finer Resin bonds still generated over twice the dust generated when using the initial metal bond grits.

The metal bond grits generated respirable crystalline silica (quartz) concentrations of 244 μg/m^3 (30 Metal) and 293 μg/m^3 (80 Metal) which are about five and six times higher than the NIOSH REL, respectively. The resin bond grits are, on average, about 26 times higher than the REL. Polishing with Resin 3 generated crystalline silica exposures of 3153 µg/m^3 or 63 times the NIOSH REL. Once the initial pass with the finer resin bond grits was completed , the remaining crystalline silica dust exposures dropped to 771 µg/m^3 (15 times the REL) for Resin 4, 553 µg/m^3 (11 times the REL) for Resin 5, and 700 µg/m^3 (14 times the REL) for Resin 6. The respirable dust concentrations from those samples collected on top of the concrete polisher are slightly lower than those collected on the operator but follow the same trend as those samples previously discussed.

Conclusions and Recommendations

Controlling exposures to occupational hazards is the fundamental method of protecting workers. Traditionally, a hierarchy of controls has been used as a means of determining how to implement feasible and effective controls. One representation of the hierarchy of controls can be summarized as follows:

- Elimination
- Substitution
- Engineering Controls (e.g. ventilation)
- Administrative Controls (e.g. reduced work schedules)
- Personal Protective Equipment (PPE, e.g. respirators)

The idea behind this hierarchy is that the control methods at the top of the list are potentially more effective, protective, and economical (in the long run) than those at the bottom. Following the hierarchy normally leads to the implementation of inherently safer systems, ones where the risk of illness or injury has been substantially reduced.

The Prep-Master 2420 concrete polisher evaluated in this survey was equipped with an engineering control, a LEV system intended to control and remove dust particles generated during the concrete polishing process. However, the dust control system needs modifications so that worker exposure to respirable crystalline silica can be reduced during concrete finishing operations. The design intent of an effective ventilation control should be to control respirable silica exposures to a level less than the NIOSH REL. Design changes could potentially include higher air capture velocities and incorporate a smooth transition at take-off locations to promote the material flow with less resistance, therefore, increasing capture efficiency. Modifying the shroud to better enclose the polishing area, reducing the gap between the shroud and the floor will also increase capture efficiency. Also, reducing the length of the hose and using smooth-walled hoses (versus the corrugated style) would reduce losses in suction between the concrete polisher and the vacuum unit. An additional evaluation is recommended to quantify the actual flow of the vacuum system and establish a correlation between the actual and the listed 10194 L/m (360 cfm) airflow.

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Appendix

Sample Location	Grit	Sample Volume (m^3)	Sample Number	Respirable Particulate Amount (µg/sample)	Respirable Particulate Concentration (µg/m^3)	Respirable Quartz Silica Amount (µg/sample)	Respirable Quartz Silica Concentration (µg/m^3)
Area #1	30 Metal	0.527	PN03111411	420	796	140	265.42
Area #2	30 Metal	0.529	PN0311145	410	775	110	208.06
Area #3	30 Metal	0.520	PN03111414	410	789	110	211.62
Area #4	30 Metal	0.530	PN0311143	370	698	88	166.10
Area #1	80 Metal	0.328	PN03111447	440	1340	100	304.49
Area #2	80 Metal	0.329	PN0311144	410	1245	110	334.15
Area #3	80 Metal	0.330	PN0311148	320	970	81	245.55
Area #4	80 Metal	0.330	PN0311149	360	1091	83	251.60
Area #1	3 Resin	0.239	PN03111433	590	2470	160	669.88
Area #2	3 Resin	0.239	PN03111440	650	2715	230	960.69
Area #3	3 Resin	0.240	PN03111429	650	2709	240	1000.40
Area #4	3 Resin	0.240	PN03111434	700	2918	240	1000.35
Area #1	4 Resin	0.309	PN03111436	430	1394	110	356.55
Area #2	4 Resin	0.309	PN03111448	500	1617	150	485.06
Area #3	4 Resin	0.310	PN03111442	480	1549	100	322.71
Area #4	4 Resin	0.310	PN03111443	440	1420	100	322.69
Area #1	5 Resin	0.269	PN03111439	610	2270	160	595.45
Area #2	5 Resin	0.269	PN03111432	520	1931	140	519.79
Area #3	5 Resin	0.270	PN03111438	430	1593	110	407.57
Area #4	5 Resin	0.270	PN03111435	390	1445	120	444.60
Area #1	6 Resin	0.269	PN03111428	440	1637	110	409.37
Area #2	6 Resin	0.269	PN03111417	450	1671	120	445.54
Area #3	6 Resin	0.270	PN03111426	430	1593	130	481.67
Area #4	6 Resin	0.270	PN03111412	420	1556	120	444.60

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