In-Depth Survey Report

Removing Mortar by Wet Grinders and Powered Chisels with On-tool Local Exhaust Ventilation

CHAOLONG QI, PHD, PE

LIEUTENANT COMMANDER, U.S. PUBLIC HEALTH SERVICE

Division of Field Studies and Engineering
Engineering and Physical Hazards Branch
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Site Surveyed:

Packer Memorial Church
Bethlehem, Pennsylvania

NAICS Code:

238140 Tuck pointing contractors

Survey Dates:

June 17-20, 2019

Surveys Conducted By:

Chaolong Qi, PhD, PE
Lieutenant Commander, U.S. Public Health Service
Senior Research Engineer

Employer Representatives Contacted:

Greg Hess
CARETTI Restoration & Preservation Services, LLC

Statistical Support:

H. Amy Feng, MS
Statistician (Health)
Division of Field Studies and Engineering

Analytical Services Provided by:

Bureau Veritas North America
Novi, MI

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Abstract

Background

Workplace exposure to respirable crystalline silica (RCS) 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 materials, such as brick, block, mortar and concrete. Construction and manufacturing tasks that cut, break, grind, abrade, or drill those materials have been associated with overexposure to dust containing RCS. Tuckpointing (repointing) removes damaged mortar from joints in masonry walls and replaces it with new mortar to restore the wall. The use of dry grinders to remove mortar results in worker overexposure to respirable crystalline silica. NIOSH researchers have been conducting a study to assess the RCS exposures associated with mortar removal when tools other than dry grinders are used. The site visit described in this report is part of that study.

Assessment

A NIOSH researcher visited a jobsite at the Packer Memorial Church, Bethlehem, Pennsylvania between June 17 to 20, 2019, and performed industrial hygiene sampling, which measured exposures to respirable dust and RCS while three workers used wet grinders and powered chisels with on-tool local exhaust ventilation (LEV) to remove mortar from stone walls. The NIOSH researcher also observed the work process in order to understand the conditions that contributed to the measured exposure.

Results

The time weighted average (TWA) RCS exposure ranged from 7.9 to 40.8 µg/m^3 when using wet grinders, and from 6.0 to 15.1 µg/m^3 when using powered chisels with the on-tool LEV. The workers' RCS exposures were well under control for both tools and their respective control measures. Excluding an outlier data point associated with wet grinders, the 95% upper confidence limit of the RCS exposure was 22.7 µg/m^3 for using wet grinders and 11.5 µg/m^3 for using powered chisels, which were both considerably lower than the Permissible Exposure Limit (PEL) by the Occupational Safety and Health Administration (OSHA) of 50 µg/m^3. They were also below the Threshold Limit Value (TLV®) of 25 µg/m^3 set by the American Conference of Governmental Industrial Hygienists (ACGIH®). If the outlier was included in the calculation, the corresponding 95% upper confidence limit for using wet grinders would become 30.1 µg/m^3, which is still 40% lower than the OSHA PEL.

Conclusions and Recommendations

The exposure levels recorded at this site indicated that the evaluated tools of wet grinders and a powered chisel with on-tool LEV were effective in reducing the worker's RCS exposures to concentrations below the OSHA PEL, and mostly below the ACGIH® TLV® as well. If workers use these types of tools and the associated

engineering control measures for full-shifts, their 8-hour TWA exposures to RCS are expected to be at similar levels below the OSHA PEL as reported, provided that other conditions remain similar. The use of these types of tools and engineering control technology for tuckpointing is a preferred solution and adheres to the hierarchy of controls.

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 Field Studies and Engineering has been given the lead within NIOSH to study the engineering aspects of health hazard prevention and control.

Since 1976, EPHB has conducted 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.

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 project

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 (RCS) 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 RCS 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. Silicosis is associated with a higher risk of tuberculosis and other lung diseases [Parks et al. 1999]. Silica has been classified as a known human carcinogen by the International Agency for Research on Cancer [IARC 1997]. Occupational exposure to respirable crystalline silica has been associated with autoimmune diseases, such as rheumatoid arthritis, and kidney disease [Parks et al. 1999, Stratta et al. 2001].

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].

Tuckpointing (repointing) removes damaged mortar from joints in masonry walls and replaces it with new mortar to restore the wall and improve its resistance to weather, prolonging its life and preventing water from penetrating the building envelope and causing damage to the structure [Gerns and Wegener 2003]. Mortar is typically removed to a depth of at least ¾-inch (in, 19 millimeters [mm]) using electric grinders, although hammers and chisels can be used [Gerns and Wegener 2003]. Other power tools are also available, including mortar routers, die grinders with diamond tools, power hammer drills and mortar chisels, and power saws [Yasui et al. 2003]. Mortar mixes contain Portland cement, lime, and sand in various proportions depending on the strength required. Type N mortar, with a minimum required compressive strength of 750 pounds per square inch (PSI), is recommended for use in exterior, above grade walls and is durable and flexible enough to replace deteriorated mortar in most walls [IMI 2002, PCA 2002, Gerns and Wegener 2003].

The use of dry grinders to remove mortar results in worker exposure to RCS 2 to 1500 times the NIOSH Recommended Exposure Limit (REL) of 50 micrograms per cubic meter (µg/m^3). Even with engineering controls (i.e., on-tool local exhaust ventilation [LEV]), the use of a respirator with an appropriately assigned protection factor is still required [Collingwood and Heitbrink 2007]. In its Preliminary Economic Analysis for the Proposed Rule for Occupational Exposure to Respirable Crystalline Silica, the Occupational Safety and Health Administration (OSHA) reported the results of 151 8-hour samples for RCS for tuckpointers [OSHA 2013]. Those sample results were in three exposure categories: outdoors, uncontrolled; outdoors, some form of LEV dust control; and under other working conditions (e.g., with limited air movement, or with inadequate attempts at dust control). Time weighted average (TWA) RCS exposures for uncontrolled, outdoor tuckpointing (83 samples) ranged from 12 to 12,616 µg/m^3, with a mean of 1,601 µg/m^3 and a median of 631 µg/m^3;

59 (71%) of the samples exceeded 250 μg/m^3. Tuckpointers working outdoors with some form of LEV (56 samples) experienced TWA RCS exposures from 10 to 6,196 μg/m^3, with a mean of 368 μg/m^3 and a median of 70 μg/m^3; 15 (27%) of the samples exceeded 250 μg/m^3. Workers tuckpointing in other conditions[1] (12 samples) had TWA RCS exposures from 146 to 75,153 μg/m^3, with a mean of 7,198 μg/m^3 and a median of 793 μg/m^3; 11 (92%) of the samples in that category exceeded 250 μg/m^3.

The tuckpointing study by Collingwood and Heitbrink [2007] reported several conditions that must be met in order for tool-mounted LEV on tuckpointing grinders to be effective: "The distance between the exhaust take-off and the uncut mortar must be minimized…the grinding wheel needs to be moved against its natural rotation so the debris is directed in the exhaust take-off…the worker must periodically stop grinding and take action to maintain (vacuum cleaner) airflow." The authors also noted that exposures increased when the distance between the tool-mounted LEV and the surface of the mortar increased, such as during plunge cuts, and when deteriorated, missing mortar provided a means for dust to escape. The discrepancy between the OSHA sampling data for tuckpointers working outdoors with some form of LEV and the conditions that must be met for the LEV to be effective indicates that there is a need to either improve the LEV for grinders or identify tools other than dry grinders that may be used to remove mortar effectively and efficiently while minimizing tuckpointers' RCS exposures. The intent of the current project is to identify tools other than dry grinders as potential alternatives for tuckpointing with lower RCS exposures.

Background for this survey

NIOSH evaluated a few tools other than dry grinders for tuckpointing in collaboration with Bricklayers and Allied Craftworkers Southern Ohio-Kentucky Regional Training Center, Batavia, Ohio. A short-term sampling strategy was used during the evaluations with an aim to quickly identify promising tools for further full-shift field evaluation. Six short-term personal breathing zone (PBZ) air samples taken from an apprentice bricklayer during active tuckpointing on a brick wall outdoors using a powered chisel without LEV [NIOSH 2017a] showed TWA RCS exposures of 72 ± 34 μg/m^3 (mean ± standard deviation, which is used hereafter for the values reported in the same format). Two additional site visits [NIOSH 2017b, NIOSH 2018a] evaluating two apprentice bricklayers' short-term RCS exposures during active tuckpointing using a powered chisel with LEV on a brick wall indoors showed TWA RCS exposure of 103 ± 54 μg/m^3 from 4 PBZ samples and 111 ± 51 μg/m^3 from 7 PBZ samples, respectively. The LEV, provided by a vacuum cleaner (model DC 2900eco, Dustcontrol, Inc, Wilmington, NC) with a manufacturer-rated maximum flowrate of 126 cubic feet per minute (CFM), operated at 87 CFM and 78 CFM, respectively during the two visits. The slightly

[1] Including in areas with limited air circulation (e.g., a courtyard, or between a wall and a plastic tarp) or where dust controls are attempted in a manner offering little or no benefit (e.g., wetting the wall before grinding, or using damaged LEV equipment).

reduced LEV flowrate found in the 2nd site visit was likely due to the addition of a pre-separator (model DC 2800, Dustcontrol, Inc., Wilmington, NC). With an increased LEV flowrate to 101 CFM by using a higher-flow vacuum cleaner (model DC Tromb 400c, Dustcontrol, Inc, Wilmington, NC), which has a manufacturer-rated maximum flowrate of 212 CFM, NIOSH [2018b] reported short-term TWA RCS exposures of 41 ± 11 μg/m^3 for 3 PBZ samples from an experienced bricklayer during active tuckpointing using a powered chisel with LEV on a brick wall indoors. The working environment, i.e., indoor vs outdoor, the flowrate provided to the LEV, and the experience of using the tool with LEV may affect the exposures. It should be noted that the actual flowrates provided by the vacuum cleaners are often considerably lower than the manufacturer-rated maximum flowrate because of the pressure loss from the hoses, pre-separators, and filters, as well as dust loading on the filters.

Overall, the results from the short-term samples when actively using a powered chisel are encouraging as they are much lower than the exposure levels from dry grinding. At actual jobsites, bricklayers do not need to conduct tuckpointing continuously throughout their full-shifts because they need to 1) often inspect the walls and identify places that need tuckpointing; 2) move to different walls or different sections of a wall upon completion; and 3) take short breaks during the operation of the heavy equipment including power tools and vacuum cleaners. The RCS exposure is expected to be much lower when a bricklayer is not actively tuckpointing due to the absence of the RCS source. Therefore, the RCS exposure during a full-shift for bricklayers is expected to be lower than the values reported from the short-term samples mentioned above when other conditions are similar.

In this survey, a NIOSH researcher conducted a site visit to evaluate the bricklayers RCS exposure at a construction site where wet grinders and powered chisels with LEV were used for tuckpointing. The field evaluation consisted of collecting PBZ air samples to assess the bricklayers' TWA respirable dust and RCS exposures while using the specific tools.

Evaluation Site and Process Description

Introduction

The evaluation site was a building with exterior walls of stone and mortar. Tuckpointing was part of a renovation project of the building. Figure 1(a) shows a picture of the building under renovation. As illustrated in the picture, the left part of the wall was completed, and the project was ongoing during the site visit for the right part of the wall where scaffolding and a fall-protection screen were set up.

Figure 1(b) shows a closeup view of the wall where tuckpointing was to be conducted. As shown in the picture, part of the mortar was broken. To make sure the mortar is consistent in appearance, unbroken mortar on the wall was also removed, and new mortar was to be repointed throughout the building.

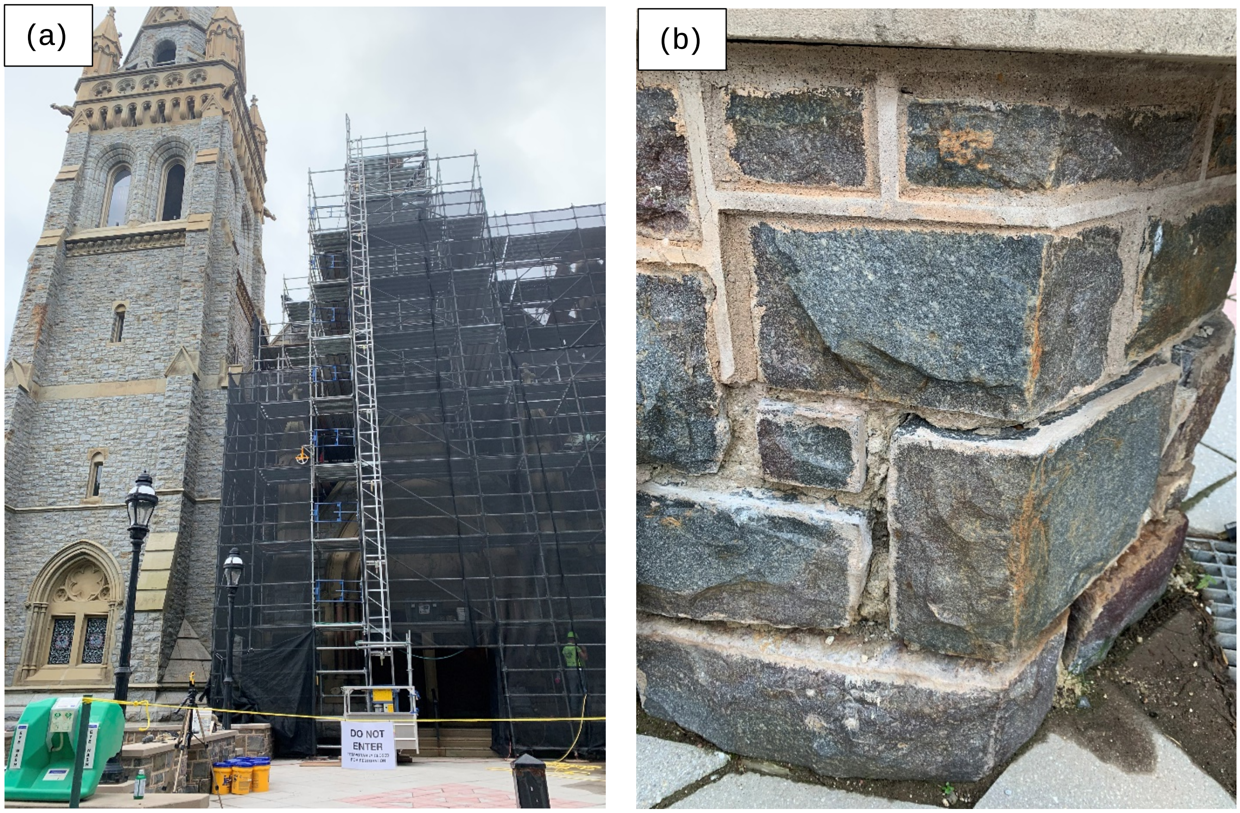

Figure 1 – (a) the stone wall building under renovation; (b) a closeup view of the wall where tuckpointing was to be conducted for the building renovation. Photos by NIOSH.

Process Description

The tuckpointing at this jobsite used a unique process because the mortar was thicker than that of regular brick walls.

Figure 2 shows a bricklayer using a handheld pneumatic wet grinder (CP9123, Chicago Pneumatic, Rock Hill, SC, running at 7,500 revolutions per minute) with a 7” diamond blade (T7H, Diamond Products, Ltd., Elyria, OH) to cut a line in the middle of the mortar. The remaining mortar was later removed by the same or a different bricklayer using a powered chisel with LEV as shown in Figure 3. The powered chisel included a rotary hammer drill (D25313 3 L-shape Type, DEWALT, Towson, MD) and a 1.5” chisel (HS1465, BOSCH, Farmington Hills, MI).

All the bricklayers at the jobsite wore elastomeric, full-face air-purifying respirators (3M™ 6800, the 3M Company, Saint Paul, MN) with P100 cartridges (3M™ Particulate Filter 2091, the 3M Company, Saint Paul, MN). Other personal protective equipment (PPE) worn included hearing protection, safety shoes, and aprons.

Figure 2 – A bricklayer using a handheld pneumatic wet grinder with a diamond blade to cut a line in the middle of the mortar. Photos by NIOSH.

Figure 3 – A bricklayer using a powered chisel with LEV for tuckpointing. Photos by NIOSH.

Control Technologies

The handheld pneumatic wet grinder at the jobsite used water to suppress dust as a control measure. The grinder, as shown in Figure 4(a), supplied water through a water spray nozzle pointing at the edge of the diamond blade. During operation, water continuously flows through a hose connected at the end of the grinder handle and was controlled by a shutoff valve. Each bricklayer may use different water flow rates by adjusting the valves on their grinders per their own preferences. Therefore, the water flowrate was not monitored in this survey.

A 13-gallon wet/dry vacuum cleaner (3931A-PB, BOSCH, Farmington Hills, MI) provided the LEV for each powered chisel. This vacuum cleaner has a manufacturer-rated maximum flowrate of 130 CFM. The actual flowrate of the LEV was not monitored during the survey, but it is likely to be close to 87 CFM reported by NIOSH [2017b] from a vacuum cleaner with similar setup and manufacturer-rated maximum flowrate.

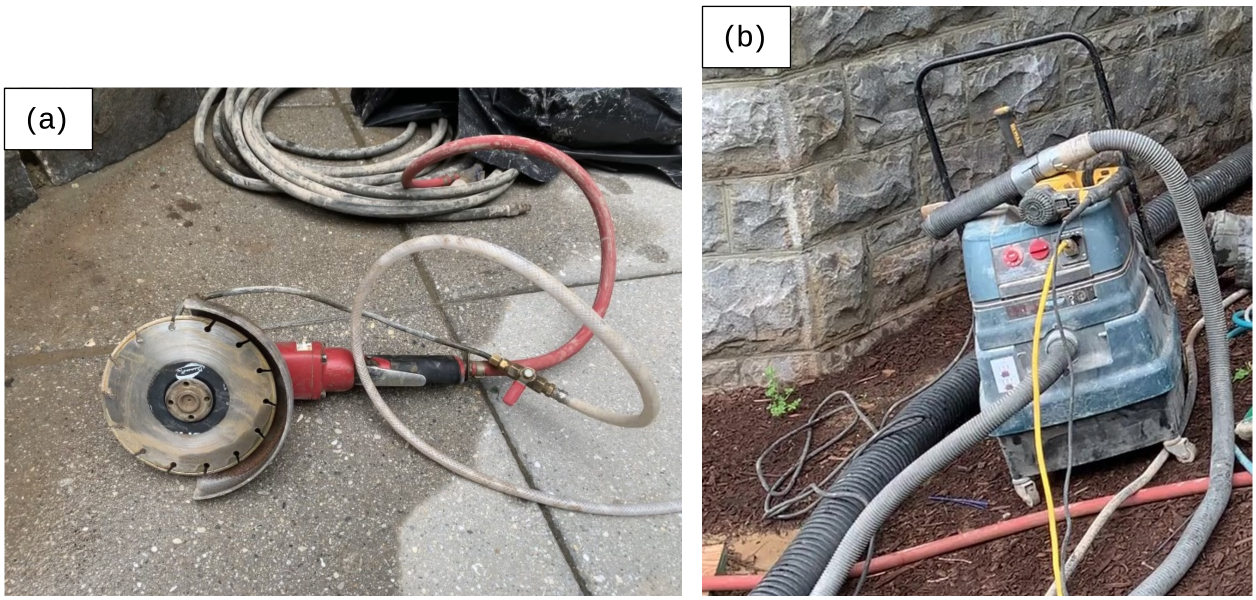

Figure 4 – (a) a handheld pneumatic wet grinder used to remove mortar; (b) a 13-gallon wet/dry vacuum cleaner providing LEV to a powered chisel. Photos by NIOSH.

Occupational Exposure Limits and Health Effects

The objective of implementing control technologies in this project is to reduce workers' occupational exposure to levels below the corresponding Occupational Exposure Limits (OELs). As a guide to the evaluation of the hazards posed by workplace exposures, NIOSH investigators use mandatory and recommended 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 PELs [29 CFR 1910.1000, 2016] 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 2018]. 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. 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) PPE (e.g., respiratory protection, gloves, eye protection, hearing protection).

Respirable Crystalline Silica Exposure Limits

NIOSH recommends an exposure limit for RCS of 50 µg/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].

$$\mu g S_i O_2/m^3 = \frac{\mu gQ + \mu gC + \mu gT + \mu gP}{V} \qquad (1)$$

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 RCS is 50 µg/m^3 as an 8-hr TWA [29 CFR 1926.1153, 2019]. The ACGIH TLV for α-quartz (the most abundant toxic form of silica, stable below 573°C) and cristobalite (respirable fraction) is 25 µg/m^3 [ACGIH 2018]. The TLV is intended to mitigate the risk of pulmonary fibrosis and lung cancer.

Methodology

Sampling Strategy

On all four sampling days, one sample was taken for each sampled worker during their use of the same tools (wet grinder or powered chisel). The total sampling time for each sample reflects the period sampled while the worker was using the specific tools. On all four days, the workers either used the same tools for the full-shifts or changed the tools once. This sampling strategy allows the evaluation of the TWA exposures associated with the specific tools.

Sampling Procedures

Air samples for respirable dust were collected at a flow rate of 4.2 liters per minute (L/min) using a battery-operated sampling pump (Gilian GilAir Plus, Sensidyne LP, Clearwater, FL) calibrated before and after each day’s use using a DryCal Primary Flow Calibrator (Bios Defender 510, Mesa Laboratories, Inc., Lakewood, CO). For PBZ samples, a sampling pump was clipped to the sampled worker’s belt worn at his waist. The pump was connected via Tygon® tubing and a tapered Leur-type fitting to a pre-weighed, 37-mm diameter, 5- 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 (model GK2.69, Mesa Laboratories, Inc., Lakewood, CO). At a flow rate of 4.2 L/min, the GK2.69 cyclone has a 50% cut point of (D_{50}) of 4.0 µm. 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 bricklayers' shirts near their breathing zone. In addition to the air samples, two field blank samples were taken on each sampling day. Three bulk dust samples (two from the vacuum cleaner and one from the vacuum hose) were also collected in accordance with NIOSH Method 7500 [NIOSH 2003].

The filter samples were analyzed for respirable dust 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) and each filter was passed over the neutralizer before weighing. The limit of detection (LOD) and the limit of quantitation (LOQ) of the respirable dust analysis are listed in Table 1.

Table 1 – The limit of detection (LOD) and the limit of quantitation (LOQ) for all the sample analysis.

	Air Samples (µg/sample)				Bulk Samples (%)		
	respirable dust	quartz	cristobalite	tridymite	quartz	cristobalite	tridymite
LOD	20	5	5	10	0.3	0.3	0.5
LOQ	58	17	17	33	0.83	0.83	1.7

Crystalline silica analysis of air and bulk dust samples was performed using X-ray diffraction according to NIOSH Method 7500 [NIOSH 2003]. The LODs and LOQs for quartz, cristobalite, and tridymite in both air samples and bulk samples are also listed in Table 1.

Results

Silica Content in Air and Bulk Samples

No respirable dust or crystalline silica was detected on any of the field blank samples. The three bulk dust samples contained 27%, 46% and 44% of quartz, respectively. In comparison, the four bulk dust samples in NIOSH's studies at Allied Craftworkers Southern Ohio-Kentucky Regional Training Center contained 49% [2017a], 47% [2017b], 28% [2018a], and 28% [2018b] of quartz, respectively. No cristobalite or tridymite was detected in the bulk dust samples.

Table 2 presents the respirable dust and RCS masses reported for every air sample collected in this survey. All the air samples contained at least 20 µg respirable dust, which is the LOD as listed in Table 1, while keeping the amount of the dust below the 2 mg upper limit specified by the NIOSH Methods 0600 [NIOSH 1998]. All but two air samples had detectable amounts of quartz. Neither tridymite nor cristobalite was detected in any air samples. Thus, only the quartz results were used in the calculation of the crystalline silica content of the air samples. The two air samples with quartz below the LOD were estimated to have LOD/SQRT(2) quartz (3.5 µg based on the LOD listed in Table 1) following Hewett and Ganser [2007].

Table 2 – Respirable Silica Masses, Respirable Dust Masses, and Percent Silica.

Date	Worker	Tools	Respirable dust (µg/sample)	RCS (µg/sample)	Silica content (%)
06/17/2019	Worker 1	Wet grinder	510	77	15.1
	Worker 2	Powered chisel	280	15	5.4
	Worker 3	Wet grinder*	340	38	11.2
06/18/2019	Worker 1	Wet grinder	60	6.4	10.7
	Worker 3	Wet grinder	20	3.5**	17.7
06/19/2019	Worker 1	Wet grinder	250	37	14.8
	Worker 1	Powered chisel	40	5.4	13.5
	Worker 2	Powered chisel	310	24	7.7
	Worker 3	Wet grinder	150	18	12.0
	Worker 3	Powered chisel	100	6.4	6.4
06/20/2019	Worker 1	Powered chisel	50	3.5**	7.1
	Worker 2	Powered chisel	280	16	5.7
	Worker 3	Powered chisel	220	22	10.0

Notes: * the worker used a power chisel for a short period of time during the day; data with a ** means the sampled data was below the LOD and a value of LOD/SQRT(2) was used in the calculation.

Based on the data presented in Table 2, the RCS content for each air sample was calculated and is listed in the last column. When using wet grinders, the six samples contained from 10.7 to 17.7% crystalline silica, with a mean of 13.6% and a standard deviation of 2.7%; while using power chisels, the seven samples contained from 5.4 to 13.5% crystalline silica, with a mean of 8.0% and a standard deviation of 2.9%. The 23 air samples collected in NIOSH's studies [2017a, 2017b, 2018a, and 2018b] at Allied Craftworkers Southern Ohio-Kentucky Regional Training Center contained 11.3 ± 4.7% quartz. Similar levels of crystalline silica content among all the samples from different studies suggests that the mortar removed during all these studies did not have very different silica content.

Respirable Dust and Respirable Crystalline Silica Results

Table 3 reports the TWA exposures to respirable dust and RCS for the participating workers. The sampling time for three samples was slightly over 8 hours (480 min) each. The sampling on 06/18/2019 was cut short due to rain. The sampling time for Worker 1 on 06/20/2019 represented his actual working time for the task. Since the work tasks conducted by the participating workers while using the same tools were consistent, the TWA exposures reported in Table 3, regardless of the actual sampling time, are generally comparable and considered representative of the 8-

hour full-shift exposures these workers would experience when using the same tools and control measures throughout full-shifts.

Table 3 – Respirable Dust and RCS Exposure Results

Date	Worker	Tools	Sampling time (min)	TWA respirable dust exposure (µg/m^3)	TWA RCS exposure (µg/m^3)
06/17/2019	Worker 1	Wet grinder	448.3	269.9	40.8
	Worker 2	Powered chisel	486.2	136.3	7.3
	Worker 3	Wet grinder*	511.4	158.0	17.7
06/18/2019	Worker 1	Wet grinder	190.8	74.3	7.9
	Worker 3	Wet grinder	69.1	68.7	12.2*
06/19/2019	Worker 1	Wet grinder	395.0	149.4	22.1
	Worker 1	Powered chisel	157.5	59.9	8.1
	Worker 2	Powered chisel	551.9	133.0	10.3
	Worker 3	Wet grinder	297.2	119.7	14.4
	Worker 3	Powered chisel	237.9	99.7	6.4
06/20/2019	Worker 1	Powered chisel	138.6	85.4	6.0*
	Worker 2	Powered chisel	401.5	167.2	9.6
	Worker 3	Powered chisel	341.2	151.2	15.1

Notes: * the worker used a power chisel for a short period of time during the day; data with a ** means the sampled data was below the LOD and a value of LOD/SQRT(2) was used in the calculation.

The focus of this research was to evaluate task-based exposure by comparing the TWA exposure data when using tools other than dry grinders with their respective engineering control measures. Extrapolating those task- and shift-based TWAs into an 8-hour TWA exposure was not helpful to the comparisons of tools and engineering control effectiveness, thus was not conducted.

When using wet grinders, the TWA exposures ranged from 68.7 to 269.9 µg/m^3 for respirable dust, and from 7.9 to 40.8 µg/m^3 for RCS; while using power chisels, the TWA exposures ranged from 59.9 to 167.2 µg/m^3 for respirable dust, and from 6.0 to 15.1 µg/m^3 for RCS.

Data analyses and discussions

Table 4 – Summary Statistics of Data Analyses

Tools	TWA respirable dust exposure (µg/m^3)	TWA RCS exposure (µg/m^3)	Silica content (%)
Wet grinder	140.0 ± 73.6	19.2 ± 11.6	13.6 ± 2.7
Powered chisel	119.0 ± 38.4	9.0 ± 3.1	8.0 ± 2.9

Table 4 lists a summary of the statistics from the data analyses. The silica content in the air samples collected when using powered chisels was significantly lower than that when using wet grinders (P = 0.004). Both sets of data from air samples were also significantly lower than the silica content in the three bulk dust samples (P = 0.05 between bulk dust samples and air samples associated with wet grinders; and

P = 0.03 between bulk dust samples and air samples associated with power chisels). The different silica contents observed from the three sets of samples are likely due to the dependency of the silica content on the particle size.

All the TWA respirable dust exposures reported in Table 3 were well below the 5 mg/m^3 OSHA PEL for Particulates Not Otherwise Regulated. However, since this dust contained RCS, the observed RCS exposures must be compared with the RCS PEL in order to determine whether exposures were successfully controlled.

The TWA exposures were not significantly different between using wet grinders and powered chisel (P = 0.548 for respirable dust and P = 0.085 for RCS). However, the TWA RCS exposures for using both tools were considerably lower than the OSHA PEL or NIOSH REL of 50 µg/m^3.

The RCS exposure data were found to be log-normally distributed. However, Worker 1's exposure on 06/17/2019 (40.8 µg/m^3) exceeded more than 1.5 times the inter-quartile-range (IQR) above the third quartile (36.7 µg/m^3) of the six samples associated with wet grinders. The worker reported to be using a wet grinder for this task for the first time. Thus, this sample was determined to be an outlier based on Tukey's method of identifying outliers [1977], and only the other five samples were used in the subsequent analyses. As shown in Table 3, the same worker's TWA RCS exposure was much lower in the two subsequent sampling periods, which was likely due to improved operation of the tool with its control measure. The summary statistics are listed in Table 5.

Table 5 - Summary Statistics and 95% Confidence Limits of the Geometric Means

	Tools	Number of Samples	Geometric Mean	95% Confidence Limits of Geometric Mean		Geometric Standard Deviation
TWA RCS exposure (µg/m^3)	Wet grinder	5*	14.0	8.6	22.7	1.48
	Powered chisel	7	8.6	6.4	11.5	1.37

Notes: * an outlier sample was not included in the analyses.

As listed in Table 5, the workers' RCS exposures were well under control for both tools and their respective control measures. The 95% upper confidence limits of both analyzed data sets were considerably lower than the OSHA PEL and NIOSH REL of 50 µg/m^3. They were also below the ACGIH® TLV® of 25 µg/m^3. It should be noted that the aforementioned outlier was not included in the statistical calculation. If the outlier was included in the calculation, the geometric mean of the TWA RCS exposure for all six samples when using wet grinders would become 16.7 µg/m^3, and the corresponding 95% upper confidence limit would become 30.1 µg/m^3, which is still 40% lower than the OSHA PEL.

As described earlier, the tuckpointing at this jobsite used a unique process of cutting a line in the middle of the mortar by using a wet grinder, followed by removing the remaining mortar with a powered chisel. This process may not be applicable to all the tuckpointing jobs. Wet operation is not desirable for some buildings because of the concern of water penetration into the building envelop as well as the potential staining of the walls. Powered chisels that work well for stone walls may not be desirable for brick walls due to the increased chipping of softer wall materials. For the unique process used at this jobsite, wet grinding not only removed a portion of the mortar, but also broke the integrity of the mortar, making it easier to remove the remaining mortar with the powered chisels. If wet grinders are not used, it might take more effort to remove all the mortar with the powered chisels alone, potentially increasing the RCS exposures to levels higher than the values reported in this survey.

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 controls can be summarized as follows:

- Elimination
- Substitution
- Engineering Controls (e.g., ventilation)
- Administrative Controls (e.g., reduced work schedules)
- 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.

From this survey, the workers' TWA RCS exposures were well below the OSHA PEL. These results indicate that the wet grinder and powered chisel with their respective engineering control measures used in this survey effectively controlled the dust emissions and reduced the workers' exposures. If workers use these types of tool and the associated engineering control measures for full-shifts, their 8-hour TWA exposures to RCS are expected to be at similar levels below the OSHA PEL as reported, provided that other conditions remain similar. When applicable, the use of these types of tool and engineering control technology for tuckpointing is a preferred solution and adheres to the hierarchy of controls.

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