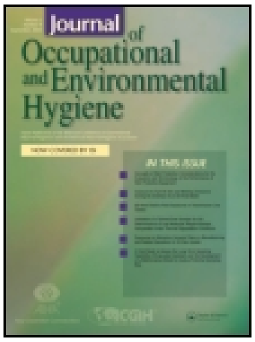

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Crystalline Silica Dust and Respirable Particulate Matter During Indoor Concrete Grinding—Wet Grinding and Ventilated Grinding Compared with Uncontrolled Conventional Grinding

Farhang Akbar-Khanzadeh,[1] Sheryl Milz,[1] April Ames,[1] Pamela P. Susi,[2] Michael Bisesi,[1] Sadik A. Khuder,[1] and Mahboubeh Akbar-Khanzadeh[1]

[1]University of Toledo Health Science Campus, Department of Public Health & Homeland Security, Toledo, Ohio
[2]Center to Protect Workers' Rights, Washington, D.C.

The effectiveness of wet grinding (wet dust reduction method) and ventilated grinding (local exhaust ventilation method, LEV) in reducing the levels of respirable crystalline silica dust (quartz) and respirable suspended particulate matter (RSP) were compared with that of uncontrolled (no dust reduction method) conventional grinding. A field laboratory was set up to simulate concrete surface grinding using handheld angle grinders in an enclosed workplace. A total of 34 personal samples (16 pairs side-by-side and 2 singles) and 5 background air samples were collected during 18 concrete grinding sessions ranging from 15–93 min. General ventilation had no statistically significant effect on operator's exposure to dust. Overall, the arithmetic mean concentrations of respirable crystalline silica dust and RSP in personal air samples during: (i) five sessions of uncontrolled conventional grinding were respectively 61.7 and 611 mg/m^3 (ii) seven sessions of wet grinding were 0.896 and 11.9 mg/m^3 and (iii) six sessions of LEV grinding were 0.155 and 1.99 mg/m^3. Uncontrolled conventional grinding generated relatively high levels of respirable silica dust and proportionally high levels of RSP. Wet grinding was effective in reducing the geometric mean concentrations of respirable silica dust 98.2% and RSP 97.6%. LEV grinding was even more effective and reduced the geometric mean concentrations of respirable silica dust 99.7% and RSP 99.6%. Nevertheless, the average level of respirable silica dust (i) during wet grinding was 0.959 mg/m^3 (38 times the American Conference of Governmental Industrial Hygienists [ACGIH] threshold limit value [TLV] of 0.025 mg/m^3) and (ii) during LEV grinding was 0.155 mg/m^3 (6 times the ACGIH TLV). Further studies are needed to examine the effectiveness of a greater variety of models, types, and sizes of grinders on different types of cement in different positions and also to test the simulated field lab experimentation in the field.

Keywords cement masons, concrete grinding, construction industry, dust reduction methods, respirable particulate matter, silica dust

Address correspondence to: Farhang Akbar-Khanzadeh, University of Toledo Health Science Campus, College of Medicine, Department of Public Health & Homeland Security, 3000 Arlington Avenue, Toledo, OH 43614; e-mail: farhang.akbar@utoledo.edu.
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INTRODUCTION

Grinding, cutting, and chipping of concrete are common in the construction industry. The task described in this report, concrete grinding (polishing, finishing), is typically performed by cement masons or concrete finishers. According to the U.S. Department of Labor,[(1)] concrete finishers (more than 200,000 in the United States), will normally smooth and finish surfaces of poured concrete, such as floors, walks, sidewalks, roads, or curbs, using a variety of hand and power tools. Other trades, including laborers, may also perform concrete grinding, adding considerably to the exposed worker population.

Recent studies have demonstrated that workers in certain construction activities dealing directly with concrete products have the potential for inhaling unacceptable levels of crystalline silica dust.[(2–8)] Excessive inhalation of crystalline silica dust has been linked to a variety of respiratory diseases, such as silicosis and lung cancer,[(9–15)] rheumatoid arthritis, scleroderma, Sjogern's syndrome, lupus, and renal disease.[(16)]

Health concerns related to silica dust inhalation have led to a number of dust reduction studies in construction.[(4–6,17–25)] The majority of these studies have focused particularly on local exhaust ventilation (LEV) and some on the wet methods in reducing silica dust during concrete grinding and other related activities. Croteau et al.[25] collected personal samples during concrete grinding with and without LEV, including three varieties of dust collection shroud configurations. The application of LEV resulted in dust reduction up to 92%. Twenty-six percent of samples in their study exceeded the permissible criteria. Flanagan et al.[4] reported on silica dust control methods during surface concrete grinding.

Using a box fan, vacuum, and shroud, these researchers showed dust reductions of 57%, 50%, and 71%, respectively. Echt and Sieber[26] reported on the performance of an LEV system that included a concrete grinder equipped with a ventilated shroud. The mean silica level for the ventilated grinding was 0.23 mg/m^3, which was considerably more than the American Conference of Governmental Industrial Hygienists (ACGIH®) threshold limit value (TLV, p. 50)[27] of 0.025 mg/m^3. Croteau et al.[6] evaluated LEV application with three ventilation airflow rates during concrete surface grinding and reported a significant reduction in silica dust exposure. Akbar-Khanzadeh and Brillhart[5] evaluated task-specific silica dust levels during concrete grinding while workers used hand-held grinders; approximately 31% were ventilated grinding. In 69% of the samples collected, the time-weighted average (TWA) concentration of silica dust exceeded the TLV of then 0.05 mg/m^3.

Thorpe et al.,[28] studying the effectiveness of dust control on cut-off saws used in the construction industry, applied wet dust suppression techniques and LEV and claimed at least 90% reduction in respirable dust. Another report showed that applying the wet dust control method in construction work can reduce the levels of silica dust up to 67%.[16] The wet dust control option may provide a reduction in silica dust levels; however, the data to demonstrate the exposure reduction using water spray during concrete grinding is scarce.[23]

Recently, Flanagan et al.[2] compiled the results of silica dust exposure monitoring in construction and suggested that additional research can help identify the parameters contributing to the highest exposure in order to target and control them. The National Institute for Occupational Safety and Health (NIOSH)[29] states that the use of water is not a feasible dust control method for many interior work situations or in the cold.

Air sampling in actual construction sites provides very useful information in characterizing real-world airborne crystalline silica dust. Nonetheless, many confounders can influence the outcome of silica dust sampling during concrete surface grinding in actual construction sites, including construction setup; surface grinding materials; hand-held grinder characteristics and attachments, such as blade size/speed and shape/structure; climatic conditions, such as wind velocity and direction; and intermittency and duration of work, workers' characteristics, and their work habits. Simulated laboratory experimentation can minimize or eliminate the effects of many confounders and can augment field sampling.

This study was conducted to evaluate the effectiveness of respirable silica dust and respirable suspended particulate matter (RSP) reduction using grinders equipped with a continuous water flow system (wet grinder) and of using grinders equipped with a local exhaust ventilation system (LEV grinder) compared with those grinders with no local dust reduction accessories (uncontrolled conventional grinders). A controlled field laboratory was used to simulate concrete surface grinding in indoor workplaces.

METHODS AND MATERIALS

Indoor Field Laboratory

Concrete grinding activities were performed in an indoor field laboratory setting: a room of approximately 7.2 × 4.8 × 4.8 m (24 × 16 × 16 ft) located in the rear of a general industrial building. The open side of the room, 4.8 × 4.8 m (16 × 16 ft), was used as an entrance; when necessary, a plastic tarp blocked the entrance off almost completely (Figure 1). A general ventilation system within the field laboratory could exhaust air to the outside. When activated, the general ventilation system had a volumetric suction flow rate of approximately 40 room air exchanges per hour.

Concrete surface grinding was performed approximately in the center of the field laboratory between the operator and general ventilation inlet, with a concrete slab set atop two 83 cm (33 inch) high sawhorses. The concrete slab was placed horizontally to simulate floor concrete surface grinding. The concrete slabs, which originated from the same demolition site with similar age and type of cement, were measured at approximately 50 × 30 cm (20 × 12 inch) for surface dimensions, with varying thicknesses ranging from 11–28 cm (4.3–11 inch). Having the equipment, training, and personnel to perform all types of concrete grinding, cutting, and drilling jobs, the concrete company provided professional and technical assistance throughout the project.

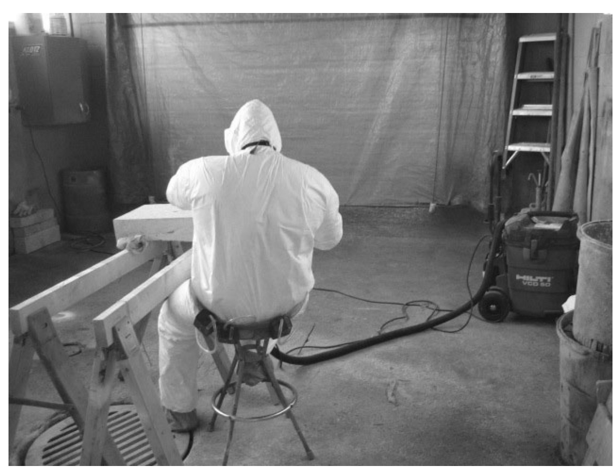

FIGURE 1. A general view of the field laboratory with a plastic tarp blocking the entrance

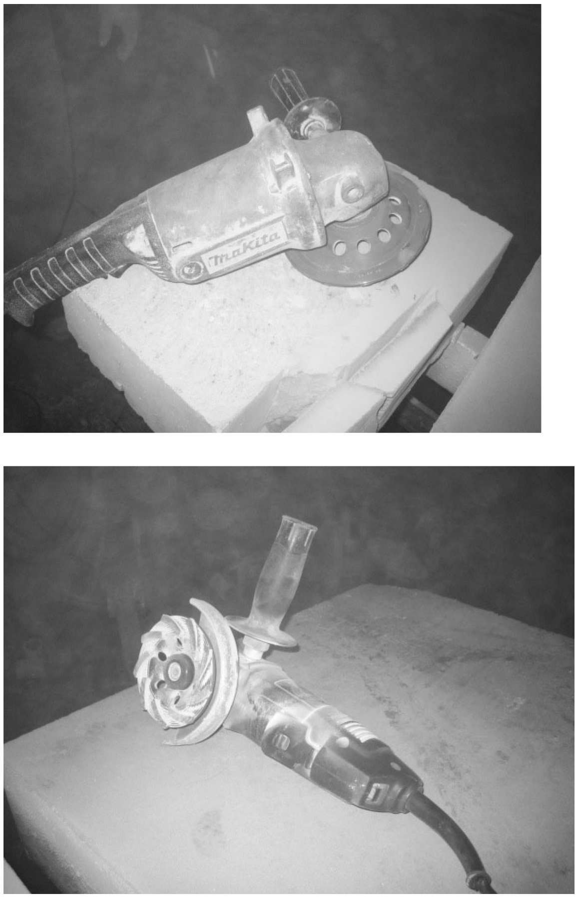

FIGURE 2. Field laboratory setup, concrete slab on the sawhorses, a 17.5-cm (7-inch) grinder (one of the 3 sizes) used for uncontrolled conventional grinding and wet grinding

Grinders

Uncontrolled conventional grinding was performed using two grinder sizes: a 17.5-cm (7-inch) grinder (model GA7001L; Makita, Anjo, Japan) (Figure 2) and a 11.4-cm (4.5-inch) grinder (model 2750G; Black & Decker, Towson, Md.).

A 17.5-cm (7-inch) grinder (model GA7001L; Makita) was used for *wet grinding*. A water hose was attached to the grinder (Figure 3), and the water flow was set by the concrete grinding operator at approximately 3 L/min (2.5–3.5). The operator explained that the 3 L/min was a critical water flow rate for this grinder, keeping the concrete surface wet during grinding while preventing water splash. Maximum deliverable water flow rate of the system used was 9 L/min.

LEV grinding was performed with a ventilated 15-cm (6-inch) grinder (model DG 150; Hilti, Schaan, Liechtenstein). The LEV consisted of a dry type vacuum cleaner (model VCD 50 L, Hilti) with a hose attaching the vacuum to the grinder (Figure 4). LEV capacity on the grinder was 50 L/s (106 ft^3/min). The capacity of LEV used in this study was higher

FIGURE 3. Wet grinding setup with water hose attached to a 17.5-cm (7-inch) grinder, and sample assembly

than a flow rate of 31 L/s (65 ft^3/min) reported by Heitbrink and Collingwood[17] and less than 66–83 L/s (140–175 ft^3/min) recommended by Flynn and Susi[30] for effective ventilated grinding.

FIGURE 4. Field laboratory setup, concrete slab on the sawhorses, a 15-cm (6-inch) grinder used for ventilated grinding with the vacuum system

Operator

The concrete grinding operator was a male of approximately 40 years of age and 175 cm (5 ft 10 inch) in height who worked primarily in the concrete construction industry. He was a laborer performing different tasks related to concrete operations and was employed by a concrete company in the business for over 25 years. The operator participated voluntarily in the study and had signed an informed consent form approved by the Institutional Review Board of the researchers' institution.

The operator was provided with the necessary personal protective equipment (PPE), including respirators (half-mask and full-face), disposable coveralls equipped with a head cover and booties, hearing protectors, goggles, and safety shoes. Prior to field activities, the operator was familiarized with the PPE and fit tested for his respirators. The operator and research team were assisted and closely supervised by one of the researchers in donning, doffing, cleaning, sanitizing, and otherwise maintaining the PPE throughout the daily activities.

Daily Activities

Prior to the start of each session, preparation work included calibrating sampling pumps and other instruments, setting up the sample train, donning personal protective equipment, and setting up the field laboratory. At the end of each session, sampling pumps were postcalibrated, collected samples were marked and placed in the sampling bag (to be submitted to the analytical laboratory), and the field laboratory was cleaned thoroughly and organized.

Air Monitoring Instruments

Air samples were collected using sampling pumps (Air-Lites; SKC, Inc., Eighty Four, Pa.) connected to a 37-mm aluminum cyclone (225-01-02; SKC). Sampling media (37-mm, 5-μm PVC filter in 3-stage cassette) were provided by an accredited analytical laboratory. Air sampling pumps were calibrated using a primary airflow meter (DryCal DC-Lite; BIOS International, Butler, N.J.). A rotameter calibrated by the primary airflow meter was used in the field to verify that the pumps were performing within the acceptable tolerance level.

A sling psychrometer (Bacharach, Inc., Pittsburgh, Pa.) was used to determine ambient temperature and relative humidity within and outside the field laboratory. During the experimentation, the median ambient temperature within the field laboratory ranged from 11–17°C (51-64°F) and was approximately 12°C (52°F) outside the laboratory. The median relative humidity (RH) within the field laboratory ranged from 47–55%. Relative humidity was approximately 46% outside the laboratory.

Monitoring Periods

The air monitoring period (sampling time) for each session was determined using analytical limit of detection (LOD) based on the standard analytical methods[31] used and our previous field respirable silica sampling.[5] In this way, the monitoring period was chosen based on the principles of collecting enough representative dust sample on the filter (at least the amount of LOD) without overloading the filter.

The operator was advised to take as many breaks as needed and feasible, just as he would take breaks during actual field surface grinding. The sampling time for all 18 sessions ranged from 5–161 min with mean (SD) of 72 (47 SD) min. The surface grinding time for these sessions ranged from 5–100 min with mean (SD) of 46 (27) min. The surface grinding time ranged from 49 to 100% [mean (SD) = 70 (16)%] of the total sampling time.

Personal and Background Air Monitoring

For personal monitoring, the operator wore two identical air sampling sets, with each set containing a suction pump, connecting tube, and filter/cassette assembly. The two sampling sets, with filter/cassette assemblies on the operator's left shoulder, were used for TWA sampling. To simulate actual concrete grinding, the pumps remained on and running during the entire experimental session, including the breaks as discussed earlier. The purpose for collecting two TWA samples side-by-side (and on the same shoulder) was quality assurance and increased data reliability. Outdoor air samples, used for background and quality assurance purposes, were collected in the yard where the general ventilation system makeup air was supplied to the field laboratory.

Field Blank Samples and Bulk Material Sampling

For quality assurance, field blank samples were collected each day and treated as active samples, except no air was passed through the filter. Bulk material samples were collected from surfaces and settled concrete dust generated during concrete surface grinding activities.

Sample Analysis

NIOSH method 7500[31] was used to collect and analyze crystalline silica (quartz) by X-ray diffraction. NIOSH method 0600[31] was used to measure RSP. The air samples were analyzed in an accredited analytical laboratory.

Statistical Analysis

Descriptive statistics was used to summarize and tabulate data. Paired t-test was used to examine the differences between the concentrations of dust taken side-by-side for quality assurance. Two-factors ANOVA was used to explain differences of dust concentration by factors of general ventilation and control methods. This analysis was followed by the Dunnett post-hoc test. All statistical analysis was performed using SPSS (version 15.0) statistical package.

RESULTS AND DISCUSSION

Overall Sampling Data

A total of 34 personal air samples (16 pairs side-by-side and 2 singles) were collected over a period of 18 sessions of concrete surface grinding. The sampling time for all 18 sessions ranged from 5–161 min. Respirable silica dust and

TABLE I. TWA Crystalline Silica Dust Concentration in Personal Samples by Control (Dust Reduction) Methods Using Hand-Held Grinders

Control Method	Sampling Session		TWA Silica Dust Concentration (mg/m^3)			Dust Reduction (%)[A]
	n	t (min)	Mean (SD)	GM (GSD)	Min–Max	
No general ventilation						
Uncontrolled conventional grinding	3	15.3	86.0 (54.2)	75.5 (1.86)	43.0–147	
Wet grinding	3	93.3	1.40 (0.39)	1.36 (1.31)	1.08–1.84	98.2
LEV grinding	3	90.0	0.161 (0.132)	0.131 (2.14)	0.077–0.314	99.8
General ventilation						
Uncontrolled conventional grinding	2	42.0	25.4 (26.6)	17.0 (3.84)	6.58–44.2	
Wet grinding	4	85.6	0.521 (0.276)	0.477 (1.59)	0.331–0.929	97.2
LEV grinding	3	90.7	0.148 (0.090)	0.132 (1.81)	0.077–0.250	99.2

Notes: TWA = time-weighted average, n = number of sessions; t = mean sampling time; SD = standard deviation; GM = geometric mean; GSD = geometric standard deviation; % = percentage dust reduction relative to uncontrolled conventional grinding.
[A]Based on arithmetic means.

RSP concentrations in the field sample blanks, in five outdoor area air samples, and in three personal air samples, collected during LEV grinding were below 10 μg/sample, the analytical limit of detection. Nondetectable values, those samples with a contaminant level below LOD, were treated according to the recommendations of Hornung and Reed.[32]

Analysis of bulk samples showed that the concrete slabs used in the experiment had an average of 26% silica (quartz). The 26% silica in the concrete slabs seems to be within a reasonable expectation because the cement is generally made of paste (<30%) and materials rich in silica (>70%), such as sand (silica base) and aggregate rock (containing silica).[2] The mean concentrations of 16 pairs of samples, taken side-by-side for quality assurance, were not significantly ($p = 0.212$) different from each other. This result supports the acceptable quality of the personal air monitoring and sample analysis.

Effectiveness of Control (Dust Reduction) Methods

Crystalline Silica Dust

Table I describes the concentration of respirable silica dust generated during uncontrolled conventional grinding, wet grinding, and LEV grinding. Figure 5 depicts the mean concentration of respirable silica dust in personal samples by control (dust reduction) methods.

Wet grinding was effective in reducing the geometric mean concentrations of respirable silica dust 98.2%. LEV grinding was even more effective and reduced the geometric mean concentrations of respirable silica dust 99.7%. Percent reduction of the arithmetic mean concentration of respirable silica dust is given in Table I. Percent reduction was calculated as $[(C_{nv} - C_v)/C_n] \times 100$, where C_{nv} = concentration of dust with no local dust control and C_v = concentration of dust with local dust control.

Two-factors (general/no general ventilation, control methods) ANOVA revealed significant differences in respirable silica dust concentrations for control methods only. The concentration of respirable silica dust was not significantly different ($p = 0.191$) when collected in the field laboratory with or without the general ventilation. This lack of significance may partially be due to the less than favorable number of samples (sessions).

On the other hand, the lack of significance may be justified by the fact that the general ventilation is competing with local dust control to capture the particles, pulling them out of the grinder shroud into the worker's breathing zone, which in turn neutralizes the dust reducing benefits of general ventilation.

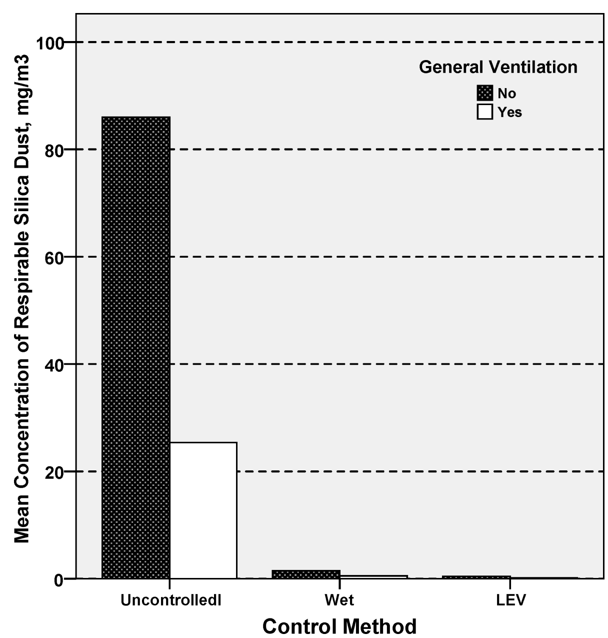

FIGURE 5. Mean concentration of respirable crystalline silica in personal samples by dust reduction methods using hand-held grinder

TABLE II. TWA Respirable Suspended Particulate Matter Concentration in Personal Samples by Control (Dust Reduction) Methods Using Hand-Held Grinders

	Sampling Session		TWA Silica Dust Concentration (mg/m^3)			
Control Method	**n**	**t (min)**	**Mean (SD)**	**GM (GSD)**	**Min–Max**	**Dust Reduction (%)[A]**
No general ventilation						
Uncontrolled conventional grinding	3	15.3	866 (492)	775 (179)	435–1400	
Wet grinding	3	93.3	17.4 (7.76)	16.4 (1.51)	12.5–26.4	97.9
LEV grinding	3	90.0	2.17 (1.85)	1.71 (2.29)	0.860–4.29	99.8
General ventilation						
Uncontrolled conventional grinding	2	42.0	228 (218)	168 (3.20)	74.0–383	
Wet grinding	4	85.6	7.77 (3.44)	7.29 (1.48)	5.27–12.8	95.7
LEV grinding	3	90.7	1.82 (0.825)	1.71 (1.53)	1.23–2.76	99.0

Notes: TWA = time-weighted average, n = number; t = time; SD = standard deviation; GM = geometric mean; GSD = geometric standard deviation; % = percentage dust reduction relative to uncontrolled conventional grinding.
[A]Based on arithmetic means.

The counteraction of general ventilation and LEV during concrete grinding may deserve further investigation. The concentration of respirable silica dust were significantly different ($p = 0.003$) within the three methods of uncontrolled conventional, wet, and LEV grinding. The post hoc test (Dunnett, 2-sided) revealed that the uncontrolled conventional grinding generated significantly higher respirable silica dust than either the wet grinding ($p = 0.003$) or the LEV grinding ($p = 0.003$). There was no difference ($p = 0.999$) in the concentration of respirable silica dust sampled by the wet grinding and the LEV grinding. The much higher concentration of the respirable silica dust sampled during uncontrolled conventional grinding sessions than those sampled during either the wet grinding or the LEV grinding, combined with a less than favorable sample sizes, might have masked any possible difference between the wet grinding and the LEV grinding.

Respirable Suspended Particulate Matter (RSP)

Table II describes the concentration of RSP in the personal samples generated during uncontrolled conventional grinding, wet grinding, and LEV grinding. Figure 6 illustrates the mean concentration of RSP in personal samples by dust reduction methods.

Wet grinding was effective in reducing the geometric mean concentrations of RSP 97.6%. LEV grinding was even more effective and reduced the geometric mean concentrations of RSP more than 99.6%. Percent reduction of the mean (arithmetic) concentration of respirable silica dust is given in Table II. Percent reduction was calculated as previously explained.

Two-factors (general/no general ventilation, control methods) ANOVA revealed significant differences in RSP concentrations for control methods only. The concentration of RSP was not significantly different ($p = 0.149$) when collected in the field laboratory with or without the general ventilation. The concentration of RSP was significantly different ($p = 0.002$) within the three methods of uncontrolled conventional, wet, and LEV grinding. The post hoc test (Dunnett, 2-sided) revealed that the uncontrolled conventional grinding generated significantly higher RSP than did either the wet grinding ($p = 0.003$) or the LEV grinding ($p = 0.002$). But there was no significant difference ($p = 0.998$) in the concentration of RSP sampled by the wet grinding and the LEV grinding.

Exposure Assessment

The findings of this pilot study indicate that the application of wet grinding or LEV grinding methods will reduce the levels of respirable silica dust considerably. Because the means

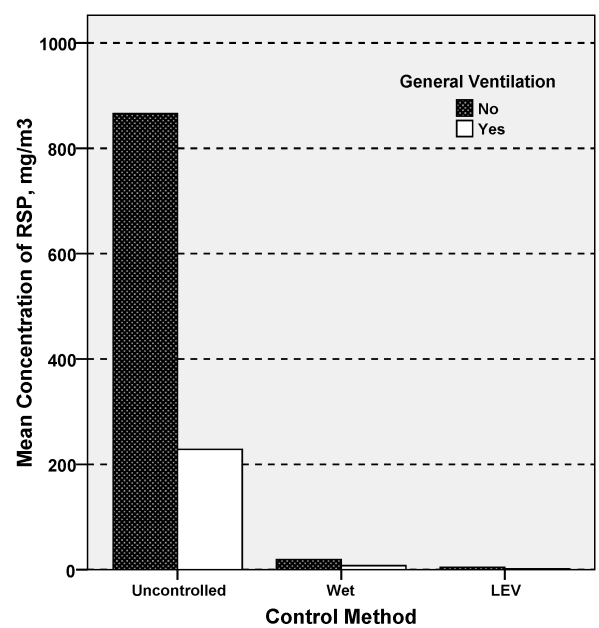

FIGURE 6. Mean concentration of respirable suspended particulate matter (RSP) in personal samples by dust reduction methods using hand-held grinders

of dust levels "with the general ventilation" or "without the general ventilation" were not significantly different, the concentrations of respirable silica dust sampled under the two conditions can be combined. Thus, the average levels of respirable silica dust during wet grinding became 0.959 mg/m^3 (38 times the ACGIH[27] TLV of 0.025 mg/m^3, assuming each session continued for an 8-hr shift period) and during LEV grinding became 0.155 mg/m^3 (6 times the TLV). Because the focus of this study was on the respirable silica dust reduction, no exposure assessment is performed here for RSP. RSP sampling was done to show the extent of respirable dustiness during the concrete grinding activities.

The results of this study indicate that with the application of current dust reduction accessories for concrete surface grinding, the levels of respirable silica dust may not be reduced to below the acceptable criterion. Therefore, an appropriate respirator may also be needed to further reduce silica dust inhalation during concrete surface grinding. In agreement with our study, other studies considering dust reduction accessories (engineered dust reduction methods) and their effects on dust generation rate indicate that although these methods may significantly reduce dust generation, they might not reduce respirable silica dust levels to below the current ACGIH[27] TLV of 0.025 mg/m^3. For example, Nij et al.[32] have concluded that to control silica dust in construction, the combined use of more than one dust control method may be necessary to reduce silica dust to an acceptable level. Croteau et al.[25] also showed that although the use of LEV reduced respirable dust exposure by 92%, the dust levels in personal samples exceeded the TLV (then 0.05 mg/m^3) for respirable silica 26% of the time.

Comparison with Other Studies on Wet Grinding

The results of this study support the general belief that the wet grinding option can provide a reduction in respirable silica dust levels. However, the data to demonstrate the exposure reduction using water spray in construction activities, including concrete surface grinding, is scarce.[23]

Nevertheless, there are some reports on the application of the wet dust reduction method to other construction activities that generate respirable silica dust. For instance, Thorpe et al.[28] applied the wet dust reduction method during cut-off sawing in the construction industry and reported at least 75% reduction in respirable silica dust and 90% reduction in RSP. Another report[16] showed that construction workers applying the wet dust reduction method can generally reduce the levels of silica dust up to 67%. However, the NIOSH Criteria Document[35] on respirable crystalline silica dust states that use of water is not a feasible dust control method for many interior work situations or in the cold.

Comparison with Other Studies on LEV Grinding

Characteristics of Environment and Tools

Table III compares the design and outcome of this research on the LEV grinding with those of four earlier (known to the authors) similar studies.[4–6,25] This study was conducted in a controlled, enclosed field laboratory, whereas the other four studies were conducted at various construction sites using LEV grinding combined with either natural or general ventilation. All other four studies have been performed using LEV grinding combined with either natural or general ventilation. Almost half the data in this study was collected during LEV grinding with no natural or general ventilation. Therefore, the information from our study seems to be the only one that may be extrapolated to LEV grinding in an enclosed space, which is simulating the concrete surface grinding performed in enclosed spaces such as the basements of residential and commercial buildings.

Our study used diamond grinding wheels, as did three of the other studies.[4–6] An abrasive type grinding wheel was used in three of the other studies.[4,5,25] In general, diamond wheels are used for more aggressive rough grinding and abrasive grinding is used for finer finishing work.[4] Our field observation indicates that diamond wheels are becoming increasingly popular for concrete surface grinding. One study reported that using an abrasive grinding wheel may generate up to 60% less dust than the diamond grinding wheel.[4]

In our study, three diameter sizes of grinding wheels (11.4 cm [4.5 inch], 15 cm [6 inch], and 17.5 cm [7 inch]) were used, all in the range of diameters of grinders used in the four other studies.[4,5,25] Grinder wheel diameter and speed are important factors, and in combination, they provide the surface area being ground per unit grinding time. The blade speed (rotation rate) in our study was estimated at 6000–10000 rev/min, which was within the range of those estimated in the other four studies.[4–6,25]

The flow rate of LEV in our study was kept at 50 L/s (106 ft^3/min), which was higher than the flow rate of those used in the other four studies (14.2–35.4 L/s [30–70 ft^3/min]).[4,5,25] Nevertheless, the capacity of LEV used in this study was comparable with the range of flow rates from 66–83 L/s (140–175 ft^3/min) recommended by Flynn and Susi[29] for effective LEV grinding.

Concentration of Respirable Silica Dust and RSP

When LEV grinding was performed in the field laboratory with general ventilation, the geometric means (GM) of respirable silica dust (0.106 mg/m^3) and RSP (1.32 mg/m^3) were slightly lower than those obtained by Croteau[6] (2.36 mg/m^3 and 11.2 mg/m^3) under some similar conditions as ours, such as ventilation (LEV + general ventilation) and wheel type (diamond). Overall, the GMs and the geometric standard deviations (GSDs) in our study were comparable to those of the other four studies.[4–6,25] When LEV grinding was performed in the field laboratory with no general ventilation, the GMs of respirable silica dust was 0.132 mg/m^3 and RSP was 1.71 mg/m^3. There is no other similar study known to these authors to make further comparison.

Efficiency of LEV

When LEV grinding was performed in the field laboratory with general ventilation and without ventilation, the reductions in the respirable silica dust exposure were 99.8% and 99.9%,

TABLE III. Comparison of Respirable Crystalline Silica and Respirable Suspended Particulate Matter in This Study with Other Studies on Grinding Concrete Using Hand-Held Surface Grinders

Parameter			Akbar-Khanzadeh and Brillhart[5]	Croteau et al.[6]		Flanagan et al.[4]		Croteau et al.[25]	This Study	
			LEV+Gen and LEV+Nat	LEV	LEV+ Gen	Gen (box fan)	LEV+Nat	LEV+Nat	LEV + Gen	LEV
Silica, mg/m^3	C_{No-LEV}	GM (GSD, n)	0.929 (3.12, 34)	29.16 (1.24, 5)	29.16 (1.24,5)	NR	NR	0.250 (3.40,27)	75.5 (1.86,2)	17.0 (3.84, 3)
	C_{LEV}	GM (GSD, n)	0.250 (3.08, 15)	2.36 (1.72, 6)	1.70 (1.34, 6)			0.034 (2.32,17)	0.131 (2.14,3)	0.132 (1.81, 3)
	% Reduction		73.1	91.9	94.2			86.4	99.2	99.8
RSP, mg/m^3	C_{No-LEV}	GM (GSD, n)	14.3 (3.41, 34)	165 (1.2, 5)	165 (1.2,5)	6.27 (2.44, 47)	4.87 (2.41, 154)	4.53 (3.93, 27)	168 (3.20, 2)	1.71 (1.53, 3)
	C_{LEV}	GM (GSD, n)	4.10 (2.39, 15)	11.2 (1.7, 6)	8.00 (1.4, 5)	2.71 (2.39, 73)	1.42 (2.49, 73)	0.14 (7.83, 11)	775 (179, 3)	1.71 (2.29, 3)
	% Reduction		71.3	93.2	95.2	56.8	70.8	96.9	99.0	99.8
LEV rate, L/s (ft^3/m)			NR	14.2 (30)	35.4 (70)	NR		33 (70)	50 (106)	50 (106)
Grinder diameter, cm (inch)			11.4 (4.5)	13.5 (5.3)	13.5 (5.3)	11.4 (4.5)	17.5 (7.0)	11.4 (4.5)	15 (6.0)	15 (6.0)
Wheel type			A and D	D	D	A and D	A and D	A	D	D
Condition			Various construction sites	Tent (one site open) in a shop		Nine construction sites, indoors	Outdoors, LEV	Six construction sites	Field laboratory, enclosed space	

Notes: RSP = respirable suspended particulate; % reduction = $[(C_{No-LEV} - C_{LEV})/C_{No-LEV}] \times 100$, C_{No-LEV} = concentration of dust with no LEV, and C_{LEV} = concentration of dust with LEV; NR = not reported; A = abrasive; D = diamond; C_{nv} = concentration with no local ventilation; C_v = concentration with local ventilation; GM = geometric mean; GSD = geometric standard deviation; n = number of samples (sessions); LEV = local exhaust ventilation; Gen = general ventilation; Nat = natural ventilation.

respectively, higher than those in the other four studies (73.1–94.2%).[4–6,25] When LEV grinding was performed in the field laboratory with general ventilation and without general ventilation, the reductions in the RSP exposure were 99.7% and 99.8%, respectively, higher than those obtained in the other four studies (56.8–96.9%).[4–6,25]

Limitations

Our study simulated field concrete grinding with a limited number of commercially available dust reduction accessories performed in an enclosed space (field laboratory) with controllable ambient conditions. However, due to the nature of construction work, dust reduction options may not be as effective in actual construction sites as their performance in the laboratory setting with controlled conditions.[33]

Each dust reduction method during concrete surface grinding presents a series of advantages and shortcomings. For example, shrouds used in some LEV systems (ventilated grinding) may pose problems for the worker, such as the inability to reach corners and limited visibility for the work area. Wet grinding methods generate a slurry deposit on the floor that must be disposed of; otherwise, it can pose safety issues such as electrocution or slipping.[25] Continuous water supply or electric power may not always be available at work sites to operate dust reduction accessories.[28]

Dust reduction methods need not always be factory designed and produced. For instance, an on-site designed and constructed dust reduction method involving a simple 37.5 cm (15-inch) spray bar fitted to a walk-behind surface grinder resulted in an 80% reduction in respirable dust levels.[34]

Although the need for reduced dust levels has been well documented, for many reasons (technical, economical, educational) engineering dust reduction methods are still rarely used and workers remain inadequately protected. In terms of economical reasons, the findings of Lahiri et al.[35] suggested that engineering dust reduction methods can be cost-effective in both developed and developing countries for reducing crystalline silica dust.

Administrative controls (e.g., reducing contact time) do not actually reduce airborne dust generation and are thus less than optimum. Despite evidence that respirators perform poorly as a main method of dust reduction, a survey conducted by Nij et al.[33] reported that respirator use (respiratory protection) was the preventive measure most widely used in the construction industry.

CONCLUSIONS

Use of concrete grinders with no dust reduction accessories (uncontrolled conventional grinding) generated high levels of respirable silica dust and proportionally high levels of RSP. Concrete grinders equipped with a constant water flow system (wet grinding) were effective in reducing the geometric mean concentrations of respirable silica dust and RSP 98.2% and 97.6%, respectively. Concrete grinders equipped with a local exhaust system (LEV grinding) were even more effective and reduced the geometric mean concentrations of respirable silica dust and RSP 99.7% and 99.6%, respectively. Nevertheless, the average level of respirable silica dust (1) during wet-grinding was 0.959 mg/m^3 (38 times the ACGIH-TLV of 0.025 mg/m^3, and (2) during LEV-grinding was 0.155 mg/m^3 (6 times the ACGIH-TLV).

RECOMMENDATIONS

Future research and training are needed to:

- Measure the effectiveness of a greater variety of models, types, and sizes of wet grinding and ventilated grinding accessories available in the market.
- Perform surface grinding on different types of cement and in horizontal and vertical positions to simulate floor, wall, and ceiling concrete grinding.
- Collect air samples in actual construction site activities of concrete grinding while using different types of dust reduction methods to determine the efficacy of such equipment.
- Educate workers and contractors on the effectiveness and correct applications of dust reduction accessories for concrete grinding.
- Encourage and determine market demand for effective dust reduction methods.

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REFERENCES

1. "Occupational Employment and Wages, May 26, 2005 (47-2051 Cement Masons and Concrete Finishers)." [Online] Available at http://www.bls.gov/oes/current/oes472051.htm#nat (Accessed Feb. 24, 2007).
2. **Flanagan, M.E., N. Seixas, P. Becker, B. Takacs, and J. Camp:** Silica exposure on construction sites: Results of an exposure monitoring data compilation project. *J. Occup. Environ. Hyg. 3*:144–152 (2006).
3. **Rappaport, S.M., M. Goldberg, P. Susi, and R.F. Herrick:** Excessive exposure to silica in the U.S. construction industry. *Ann. Occup. Hyg. 47*:111–122 (2003).
4. **Flanagan, M.E., N. Seixas, M. Major, J. Camp, and M. Morgan:** Silica dust exposure during selected construction activities. *Am. Ind. Hyg. J. 64*:319–328 (2003).
5. **Akbar-Khanzadeh, F., and R.L. Brillhart:** Respirable crystalline silica dust exposure during concrete finishing (grinding) using hand-held grinders in the construction industry. *Ann. Occup. Hyg. 46*:341–46 (2002).
6. **Croteau, G.A., S.E. Guffey, M.E. Flanagan, and N.S. Seisax:** The effects of local ventilation controls on dust exposure during concrete cutting and grinding activities. *Am. Ind. Hyg. J. 63*:458–467 (2002).
7. **Lumens, M., and T. Spee:** Determinants of exposure to respirable quartz dust in the construction industry. *Ann. Occup. Hyg. 45(7)*:585–595 (2001).
8. **Linch, K., W.E. Miller, R.B. Althouse, D.W. Groce, and G.M. Hale:** Surveillance of respirable crystalline silica dust using OSHA compliance data (1979–1995). *Am. J. Ind. Med. 34*:547–558 (1998).

9. **Yassin, A., F. Yebesi, R. Tingle:** Occupational exposure to crystalline silica dust in the United States, 1988–2003. *Environ. Health Perspect. 113*:255–260 (2005).
10. **Bang, K.M., J.M. Mazurek, and M.D. Attfield:** Silicosis mortality, prevention, and control—United States, 1968–2002. *MMWR 54*:401–405 (2005).
11. **Steenland, K.:** One agent, many diseases: exposure-response data and comparative risks of different outcomes following silica exposure. *Am. J. Ind. Med. 48*:16–23 (2005).
12. **Linch, K.:** Respirable concrete dust—Silicosis hazard in the construction industry. *Appl. Occup. Environ. Hyg. 17*:209–211 (2002).
13. **Kane, F.:** The campaign to end silicosis. *Job Saf. Health Quart. 8*:16–19 (1997).
14. **National Institute for Occupational Safety and Health (NIOSH):** *Request for Assistance in Preventing Silicosis and Deaths in Construction Workers*. DHHS (NIOSH) Pub. No. 96–10. Washington, D.C.: NIOSH, 1996. pp. 2–3.
15. **Freeman, C.S., and E.A. Grossman:** Silica exposures in workplace in the United States between 1980 and 1992. *Scand. J. Work, Environ. Health 2(Suppl. 2)*:47–49 (1995).
16. **National Institute for Occupational Safety and Health (NIOSH):** *Hazard Review: Health Effects of Occupational Exposure to Respirable Crystalline Silica*. DHHS (NIOSH) Pub. No. 2002–129. Washington, D.C.: NIOSH, 2002. pp. 67–79.
17. **Heitbrink, W.A., and S. Collingwood:** *Protecting Tuckpointing Workers from Silica Dust: Draft Recommendations for a Ventilated Grinder*. Silver Spring, Md.: The Center to Protect Workers' Rights, 2005. pp. 1–8.
18. **Beamer, B.R., S. Shulman, A. Maynard, D. Williams, and D. Watkins:** Evaluation of misting controls to reduce respirable silica exposure for brick cutting. *Ann. Occup. Hyg. 49(6)*:503–510 (2005).
19. **Golla, V.J., and W.A. Heitbrink:** Control technology for crystalline silica exposures in construction: wet abrasive blasting. *J. Occup. Environ. Hyg. 1*:D26–D32 (2004).
20. **Echt, A., K. Sieber, E. Jones, D. Schill, D. Lefkowitz, J. Sugar, and K. Hoffner:** Control of respirable dust and crystalline silica from breaking concrete with a jackhammer. *Appl. Occup. Environ. Hyg. 18*:491–495 (2003).
21. **Yasui, S, P. Susi, M. McClean, and M. Flynn:** Assessment of silica exposure and engineering controls during tuckpointing. *Appl. Occup. Environ. Hyg. 18*:977–984 (2003).
22. **Carlton, G.N., K.B. Patel, D.L. Johnson, and T.A. Hal:** The effectiveness of handheld ventilated sanders in reducing inhalable dust concentrations. *Appl. Occup. Environ. Hyg. 18*:51–56 (2003).
23. **Flanagan, M.E., C. Loewenherz, and G. Kuhn:** Indoor wet concrete cutting and coring exposure evaluation. *Appl. Occup. Environ. Hyg. 16*:1097–1100 (2001).
24. **Flecher, B.:** The design of local exhaust ventilation hoods for grinding wheels. *Ann. Occup. Hyg. 39*:535–543 (1995).
25. **Croteau, G., M. Flanagan, J. Camp, and N.S. Seixas:** The efficacy of local exhaust ventilation for controlling dust exposures during concrete surface grinding. *Ann. Occup. Hyg. 38*:509–518 (2004).
26. **Echt, A., and W.K. Sieber:** Control of silica exposure from hand tools in construction: grinding concrete. *Appl. Occup. Environ. Hyg. 17*:457–461 (2002).
27. **American Conference of Governmental Industrial Hygienists (ACGIH):** *Threshold Limit Values and Biological Exposure Indices*. Cincinnati, Ohio: ACGIH, 2006. pp. 6, 50.
28. **Thorpe, A., A.S. Ritchie, M.J. Gibson, and R.C. Brown:** Measurements of the effectiveness of dust control on cut-off saws used in the construction industry. *Ann. Occup. Hyg. 43(7)*:444–456 (1999).
29. "Health Effects of Occupational Exposure to Respirable Crystalline Silica." [Online] Available at http://www.cdc.gov/niosh/02-129A.html (Accessed Feb. 20, 2007].
30. **Flynn, M., and P. Susi:** Engineering controls for selected silica and dust exposures in the construction industry—A review. *Appl. Occup. Environ. Hyg. 18*:268–277 (2003).
31. National Institute for Occupational Safety and Health (NIOSH): Methods 0600 and 7500. In *NIOSH Manual of Analytical Methods (NMAM)*, 4th ed. Washington, D.C.: NIOSH, 1998.
32. **Hornung, R.W., and L.D. Reed:** Estimations of average concentration in the presence of non-detectable values. *Appl. Occup. Environ. Hyg. 5*:46–51 (1990).
33. **Nij, E., S. Hilhorst, T. Spee, et al.:** Dust control measures in the construction industry. *Ann. of Occup. Hyg. 47(3)*:211–218 (2003).
34. **Echt, A., W. Sieber, A. Jones, and E. Jones:** Control of silica exposure in construction: Scabbling concrete. *Appl. Occup. Environ. Hyg. 17*:809–813 (2002).
35. **Lahiri, S., C. Levenstein, D.I. Nelson, and B.J. Rosenberg:** The cost effectiveness of occupational health interventions: prevention of silicosis. *Am. J Ind. Med. 48*:503–514 (2005).