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The Efficacy of Local Exhaust Ventilation for Controlling Dust Exposures During Concrete Surface Grinding

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This study assessed the effectiveness of a commercially available local exhaust ventilation (LEV) system for controlling respirable dust and crystalline silica exposures during concrete grinding activities. Surface grinding was conducted at six commercial building construction sites in Seattle, WA, by cement masons. Time-integrated filter samples and direct reading respirable dust concentrations were collected using a cyclone in line with a direct reading respirable dust monitor. Personal exposure levels were determined with and without LEV, one sample directly after the other. A total of 28 paired samples were collected in which three different dust collection shroud configurations were tested. Data obtained with a direct reading respirable dust monitor were adjusted to remove non-work task-associated dust exposures and was subsequently used to calculate the exposure reduction achieved. The application of LEV resulted in a reduction in the overall geometric mean respirable dust exposure from 4.5 to 0.14 mg/m^3, a mean exposure reduction of 92%. Despite the effective control of dust generated during surface grinding, 22 and 26% of the samples collected while LEV was being used were greater than the 8 h time-weighted average permissible exposure limit (Occupational Safety and Health Administration) and threshold limit value (American Congress of Governmental Industrial Hygienists) for respirable crystalline silica, respectively.

Keywords: construction; dust control; local exhaust ventilation; silica; surface grinding

INTRODUCTION

Construction workers, particularly those involved in the cutting, grinding or drilling of concrete, brick and stone, can be exposed to excessive levels of respirable crystalline silica. The excess exposure of construction workers to respirable crystalline silica exposure has been documented in exposure assessment studies (Riala, 1988; Lumens, 1997; Lumens and Spee, 2001; Flanagan *et al.*, 2003; Rappaport *et al.*, 2003) as well as regulatory monitoring results (Lofgren, 1993; Freeman and Grossman, 1995; Linch *et al.*, 1998). The effects of construction workers' elevated exposure to respirable crystalline silica has been documented in studies which have shown that construction workers face an increased risk of contracting silicosis (Ng, 1988; Partanen *et al.*, 1995; Robinson *et al.*, 1995).

For many construction activities, local exhaust ventilation appears to be the most promising method for reducing silica dust exposures. Substitution of products with lower crystalline silica content may be possible for special circumstances, but is not readily feasible given the prevalence of silica-based materials, especially concrete, in many construction materials. Administrative controls can help bring awareness to the issue and foster the use of good practices and other control measures, but do not reduce airborne silica dust concentrations. Water spray can effectively reduce exposure levels, but is not feasible in many applications because water can result in material discoloration and expansion, building damage and wastewater disposal problems. Use of water spray controls also presents potential safety hazards, which include electrocution, slipping and potentially hypothermia.

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Of all the dust-generating activities that may be present on a construction site, the highest exposure levels to silica are often associated with the preparation of concrete surfaces using a hand-held grinder (Lofgren, 1993; Flanagan *et al*., 2003). Furthermore, site observations and conversations with construction industry professionals indicate that the grinding of concrete surfaces is common to most commercial structures that use concrete as a building material. Therefore, a high priority needs to be placed on the development and widespread use of engineering controls for reducing silica exposures during surface grinding.

A growing body of research, much of which has been summarized in a review article authored by Flynn and Susi (2003), has shown that the use of LEV can substantially reduce airborne particulate exposures generated by different construction-related activities. With respect to surface grinding, the use of LEV has been shown to reduce respirable dust exposures by 95% in a controlled field study (Croteau *et al*., 2002). A controlled field study environment is very desirable for assessing LEV effectiveness as conditions continually change at construction sites. Changes in wind speed and direction, non-work task time during monitoring, other dust sources, level of enclosure and type of surface being prepared, among other conditions, can all have a substantial effect on personal dust exposures, which compromises the ability to accurately assess the efficacy of LEV. However, testing the LEV system under field conditions is essential to confirm controlled field study results and can be looked at as a second tier in the testing process.

Respirable dust and silica exposure levels associated with LEV-equipped surface grinders have also been determined in construction site-based studies [National Institute for Occupational Safety and Health (NIOSH), 1998; Gressel *et al*., 1999; Akbar-Khanzadeh and Brillhart, 2002]. However, in these studies the lack of spatial and temporal continuity between samples collected with and without LEV being used increases the potential influence of confounding environmental factors on the results. Furthermore, the ventilation rate used in these studies was neither controlled at a specific level nor measured. Consequently, an accurate determination of exposure reduction is not possible. Exposure reduction is an important metric as it allows the practitioner to determine the suitability of LEV for reducing exposure levels in a similar manner that a respirator would be selected. Therefore, the primary objective of this study was to assess the efficacy of LEV for controlling surface grinding dust exposures in a field setting. To limit the influence of confounding factors, efforts were made to maintain a reasonable level of spatial and temporal continuity between controlled and uncontrolled samples.

MATERIALS AND METHODS

Study location

Dust control evaluations were conducted from 20 February 2001 to 30 July 2002 at six large construction sites in Seattle, WA. All of the construction sites, each of which was managed by a different prime contractor, were commercial building projects and included a public stadium, hospital building, hotel, parking garage and two office buildings. Only one site was an interior space, while all others were covered, but not completely enclosed. Surface preparation work was focused on vertical walls. In five cases, ceilings or columns were also being prepared in addition to walls. General dilution ventilation did not exist in the vicinity of the work area at any of the sites during monitoring.

Construction sites where dust control evaluations could potentially be conducted were identified through contacts in the construction industry. A site was selected for monitoring if a minimum of 4 h of surface preparation using an 11.4 cm surface grinder was expected to be performed and the equipment operator (study subject) and contractor were willing to participate. Subject participation was voluntary and in compliance with procedures approved by the University of Washington human subjects Institutional Review Board. Personal protective equipment used by the study subjects included boots, gloves, earplugs and a half-face mask mechanical filter respirator, all of which were supplied by the study subject and contractor.

Experimental design

The study utilized a paired samples design in which dust exposures for a given study subject were determined with and without LEV (in sequence). With the exception of five paired samples, dust exposure without LEV was determined prior to that of with LEV treatment. A series of one to four paired samples, ~30–45 min in duration each, were collected over the course of a work day. The collection of paired samples over a relatively short time-frame minimizes the effect of variable conditions, such as wind, type of concrete, degree of enclosure, surface preparation objective and the intermittent nature of this work task. Short duration sampling periods are commonly used in engineering control and exposure assessment studies conducted at construction sites (Thorpe *et al*., 1999; Akhbar-Khanzadeh and Brillhart *et al*., 2002; Croteau *et al*., 2002; Flanagan *et al*., 2003; Nij *et al*., 2003).

Vacuum source

An industrial vacuum (Dust Control 2700C) was used to provide ventilation airflow for the tools evaluated. The vacuum was equipped with a 23.5 cm diameter cyclone followed by a HEPA filter (99.97% efficiency). Air was conveyed from the tool to the industrial vacuum through a flexible, 5.2 m long, 3.8 cm diameter corrugated hose. Before and after the collection of each LEV treatment sample, the airflow rate was adjusted and measured with a pitot tube and the vacuum filter was cleaned as described earlier (Croteau *et al*., 2002).

Tools evaluated

A Flex LD 1509 FR (Steinheim, Germany) and Metabo WE 9-125 Quick (Nurtingen, Germany) hand-held, electric powered flat grinders were used in this study. During the study, the surface grinders were equipped with Pferd (Marienheide, Germany) EDP 61508, 11.4 cm abrasive grinding wheels. This type of tool is most typically used to produce a smooth finish on poured concrete walls and floors. A more detailed description of the hand-held surface grinder and the surface grinding work task is presented in Croteau *et al*. (2002) and Flanagan *et al*. (2003).

Both surface grinders were equipped with shrouds that covered the grinding wheel completely, allowing for a seal between the working surface and the shroud. The Flex grinder (Fig. 1a) was equipped with a shroud that was manufactured by Flex and constructed of rubber. This shroud is 17.8 cm in diameter and has 22 0.5 cm diameter holes positioned concentrically on the shroud periphery to allow the introduction of make-up air. The bottom of the Flex shroud is fitted with a metal ring, which maintains a stiff and rigid contact point with the surface. The exhaust take-off is 3.2 cm in diameter and is located on the right side of the tool. At the target airflow rate of 70 feet^3/min (c.f.m.), the shroud had a calculated face velocity of 260 feet/min (f.p.m.).

The Metabo grinder (Fig. 1b) was equipped with a Sawtec (Costa Mesa, CA) shroud, which is constructed of polyurethane. Like the Flex shroud, the exhaust take-off is located on the right side of the grinder. The Sawtec exhaust take-off is tapered and has a diameter of 4.1 cm where the take-off connects to the shroud and a 5.8 cm diameter at its opposite end where it connects to the vacuum source. The Sawtec shroud has a diameter of 14 cm, resulting in a face velocity of 420 f.p.m. In addition to having a smaller diameter than the Flex shroud, the Sawtec shroud is more flexible than the Flex shroud. Consequently, the Flex shroud is referred to as the 'rigid shroud' and the Sawtec shroud is referred to as the 'flexible shroud' from here on.

A third tool/shroud configuration, which entailed cutting the tip of a flexible (Sawtec) shroud on a Metabo grinder (Fig. 1c), was also assessed and is referred to as the 'cut shroud'. This modification allows the tip of the grinding wheel to access corners and inside edges, which is not otherwise possible, as the shroud encloses the grinding wheel. This modification is often utilized by contractors and may compromise dust capture effectiveness. In this study the tip of a flexible shroud was removed along an 8.5 cm tangent across the front end of the shroud. The resulting cut shroud was tested in the same manner as the other two tool/shroud configurations. For the 'no LEV treatment', workers were provided with a second grinder, identical to the grinder used for the 'LEV treatment', except it was not equipped with a ventilation shroud, but was equipped with a safety guard.

It was not feasible to use all three tool/shroud configurations at each site as it was not known at the beginning of the day how many tests could be conducted and it was also thought that changing tools might be disruptive to the worker. Furthermore, workers on occasion would indicate a willingness to use only one of the three tools.

Exposure monitoring

Dust control effectiveness was assessed by determining personal exposure levels to respirable dust during surface grinding with and without the use of LEV. Both real time and gravimetric respirable dust exposure levels were determined with a light scattering photometer fitted with a BGI cyclone pre-selector (Waltham, MA) and PVC filter. The filter samples were used to describe actual exposure levels to respirable dust and crystalline silica, assess regulatory compliance and compare conditions between work sites. The pDR data were used to evaluate the effectiveness of the LEV controls.

The pDR and air sampling pump (Gilian, Clearwater, FL), calibrated to a flow rate of 2.65 l/min and set to a data logging period of 1 min, were placed in a small backpack which was worn by the worker being monitored. The sampled airstream entered the BGI cyclone by way of silicon tubing 30 cm in length and 0.5 cm in diameter that was affixed to the top of the worker's left shoulder. Air sampling trains were calibrated pre- and post-sampling using a DryCal® primary calibration standard (BIOS, Butler, NJ). The Occupational Safety and Health Administration (OSHA) 8 h time-weighted (TWA) permissible exposure limit (PEL) was calculated based on equation 1. The quotient of the respirable dust exposure and OSHA PEL was determined to establish the degree of compliance with the PEL.

$$\mathrm{OSHAPEL} = 10/(\%\mathrm{SiO_2} + 2) \qquad (1)$$

where $\%SiO_2$ is the percentage of the respirable dust mass that is crystalline silica.

All work sessions were observed by a researcher who recorded the following variables on a 1 min basis: whether the worker was actively engaged in the work task (surface grinding) or not, if the working

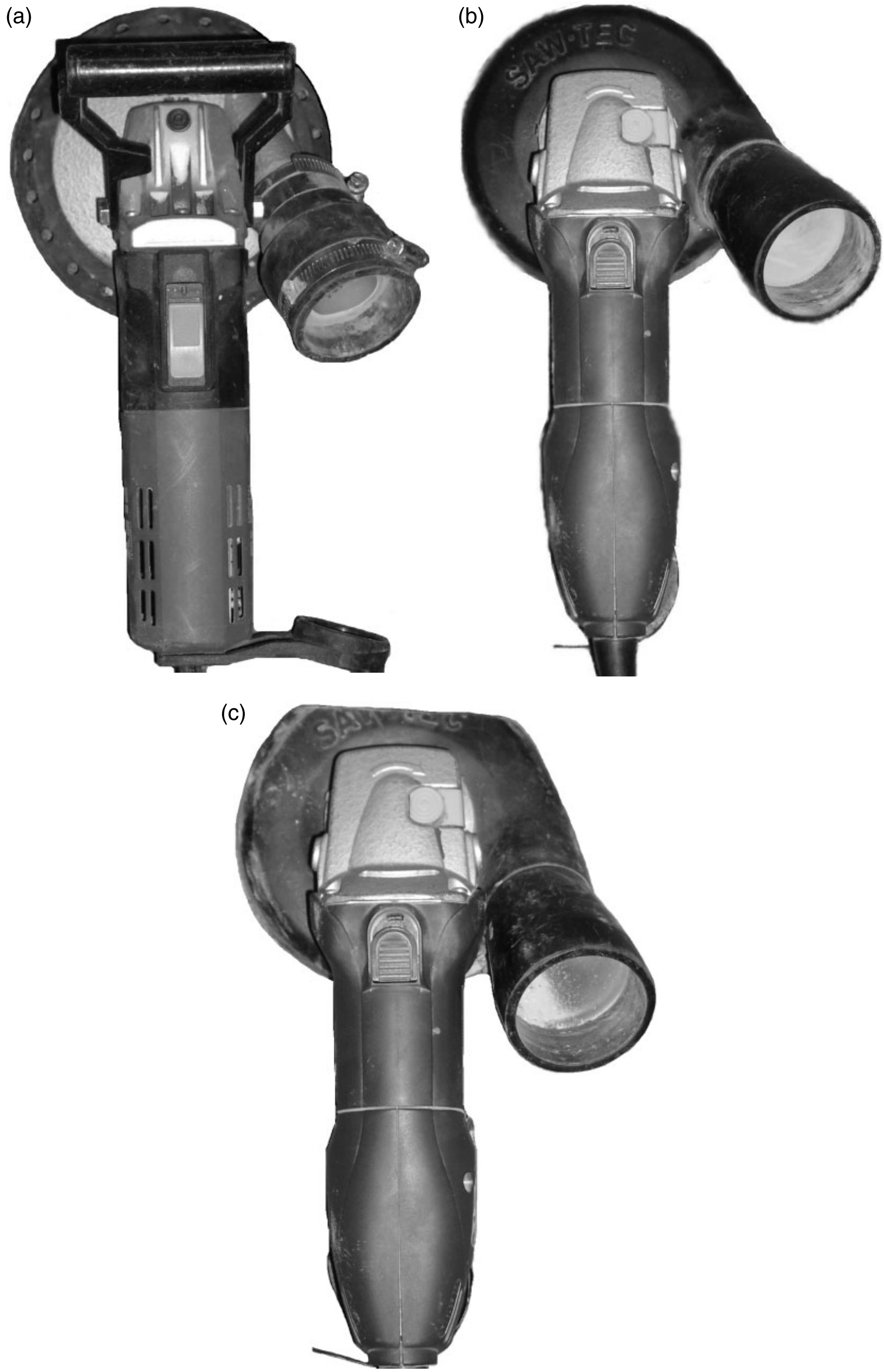

Fig. 1. Surface grinding tools evaluated. (a) Flex LD 1509 FR, 'rigid shroud'; (b) Metabo WE 9-125 Quick, 'flexible shroud'; (c) Metabo WE 9-125, 'cut shroud'.

surface was an edge or flat surface, the presence of other dust sources and the observed orientation of the wind to the worker. It was anticipated that the actual task time spent surface grinding during a work session could change appreciably between different work sessions. Consequently, to provide a better estimate of dust exposure during the actual surface grinding work task, worker observations and pDR data were merged in a single database. Task-based exposure levels were then determined by excluding exposure measurements during time periods >1 min in length in which the task was not performed. The resulting exposure metric is referred to as the 'task pDR exposure level', as opposed to the 'total pDR exposure level'.

The respirable dust mass of all samples collected was determined gravimetrically using National Institute for Occupational Safety and Health (NIOSH) Method 0600 (NIOSH, 1994a). Filters were equilibrated in a dessicator for a minimum of 24 h prior to tare and final weighing. After the dust mass was determined, individual filters were placed in a crucible, ashed and subsequently analyzed for quartz and cristobalite by infrared spectrometry using NIOSH Method 7602 (NIOSH, 1994b). Laboratory quality was assessed by the collection and analysis of field blanks at a rate of 10%. For quartz analysis, a standard was analyzed twice for every 10 samples and variation was found to be <5%. The detection limit for both respirable dust and quartz was 5.0 μg. Cristobalite levels were all less than the detection limit of 5.5 μg and were not included in determining respirable crystalline exposure levels.

Data analysis

Analytical results for quartz found to be less than the limit of detection (LOD) were entered into the analysis as 50% of the LOD as per the recommendation of Hornung and Reed (1990). pDR 1 min average readings that were less than the minimum instrument response level of 0.001 mg/m^3 were averaged into the mean task exposure calculation as 0. Exposure reduction was based on a comparison of the task pDR exposure levels, for each pair of matched samples, which were collected with and without LEV (equation 2):

$$\%\,\text{reduction} = [(C_{\text{nv}} - C_{\text{v}})/C_{\text{nv}}] \times 100 \qquad (2)$$

where C_{nv} and C_{v} are the task pDR respirable dust exposure levels for a matched sample pair under the no LEV and LEV treatments, respectively.

Establishing the statistical significance between exposure levels with and without the use of LEV was determined through a paired samples *t*-test. Linear statistical models were developed to assess the combined effects of work characteristics (activity, site and tool) utilizing percent reduction in the task-based pDR measurements as the independent variable. In order to control for the possible effect of dust level in these models, the task-based pDR dust exposure level without LEV was also included as a covariate. Model development was an iterative process whereby predictors (site, tool/shroud and activity) were added and their overall effect on the model was considered.

RESULTS

A total of 28 paired personal air monitoring samples were collected at six different construction sites, over 11 monitoring days, using nine different study subjects. The mean ± SD sample duration time was 32.6 ± 11.0 min for the no LEV treatment and 47.7 ± 8.7 min for the LEV treatment. The mean ± SD task monitoring periods with and without LEV were 80.5 ± 8.7 and 79.8 ± 11.1% of the total monitoring period, respectively.

With a few exceptions, both direct reading and gravimetric exposure data were collected for each paired sample. A single tool/shroud configuration was tested at four of the six sites, with two and three tool/shroud configurations being tested at the other two sites. A total of nine paired samples were collected in which the rigid shroud was being used, with eight and 11 paired samples being collected while the flexible and cut shrouds were being used, respectively. Out of 28 total paired samples, 23 were obtained while only wall surfaces were being prepared. Of the remaining five samples, three were collected while columns and walls were being prepared and two paired samples were collected while ceilings and walls were being prepared.

The mean ± SD detection limit for both respirable dust and quartz was 0.07 ± 0.02 mg/m^3 for the no LEV treatment and 0.04 ± 0.01 mg/m^3 for the LEV treatment. For the no LEV treatment, a single sample (4%) was less than the detection limit for respirable dust and four samples (14%) were less than the quartz detection limit. For the LEV treatment, 39 and 67% of the samples were less than the respirable dust and quartz detection limits, respectively. Although there was a large fraction of samples that were less than the detection limit, the detection limit of the non-detected samples was less than health-based exposure guidelines. The mean detection limit for the non-detected samples was 0.02 mg/m^3 for both respirable dust and crystalline silica, which is substantially lower than the American Congress of Governmental Industrial Hygienists (ACGIH, 2003) 8 h time weighted average threshold limit value (TLV) for respirable dust (3 mg/m^3) and crystalline silica (0.05 mg/m^3).

Relatively precise control of the LEV rate was achieved. The overall mean ± SD ventilation rate of 69.6 ± 3.6 c.f.m. did not vary considerably from the target ventilation rate of 70 c.f.m. and the pre- and post-work session ventilation rate measurements were not significantly different ($P > 0.1$). The percent respirable quartz content of the concrete being prepared at the five constructions sites where monitoring was conducted ranged from 3 to 10%.

Personal respirable dust monitoring results, determined both gravimetrically and with a direct reading instrument, were approximately log-normally distributed and were natural log transformed prior to analysis. The overall geometric mean respirable dust exposure without LEV was 4.53 mg/m^3, which was significantly higher ($P < 0.0001$) than the overall geometric mean exposure of 0.14 mg/m^3 with LEV in use (Table 1). Similarly, geometric mean respirable crystalline silica concentrations were reduced by the use of LEV from 0.250 to 0.034 mg/m^3 (Table 2).

Considerable variability in the geometric mean exposure levels is noted between the different construction sites. For respirable dust exposures without LEV, the geometric mean exposure level ranges from 0.78 mg/m^3 at Site 4, to 12.70 mg/m^3 at Site 6. Similar between-site variability is observed for the geometric mean respirable dust exposure levels for the with LEV treatment, as well as for the respirable crystalline silica exposure levels with and without LEV. Considerable variability in exposure levels is also noted when the results are presented by either tool/shroud type or activity. The large geometric standard deviations for some of the categories in Table 1 are

Table 1. Geometric mean (GSD) personal gravimetric respirable dust exposure levels (mg/m^3)

	Independent variable	n	No LEV		With LEV	
			Samples < DL[a]	GM (GSD)	Samples < DL	GM (GSD)
All data		27	1	4.53 (3.93)	11	0.14 (7.83)
Site	1	5	0	7.33 (3.54)	1	0.25 (11.16)
	2	6	0	3.74 (1.55)	3	0.07 (5.35)
	3	5	0	7.77 (1.64)	0	1.33 (2.24)
	4	5	1	0.78 (7.20)	5	0.02 (1.24)
	5	2	0	6.57 (2.41)	0	0.55 (9.79)
	6	4	0	12.70 (1.86)	2	0.04 (2.83)
Shroud	Rigid	9	0	9.17 (1.91)	4	0.11 (7.55)
	Flexible	8	1	1.72 (6.51)	5	0.08 (7.30)
	Cut	10	0	5.22 (2.65)	2	0.32 (8.12)
Activity	Walls	22	1	4.18 (4.43)	11	0.10 (7.81)
	Ceiling and walls	2	0	6.57 (2.41)	0	0.55 (9.79)
	Columns and walls	3	0	6.41 (1.76)	0	0.81 (1.87)

[a]Number of samples with a respirable dust mass that was less than the detection limit.

Table 2. Geometric mean (GSD) personal gravimetric respirable quartz exposure levels (mg/m^3)

	Independent variable	n	No LEV		With LEV	
			Samples < DL[a]	GM (GSD)	Samples < DL	GM (GSD)
All data		27	4	0.250 (3.40)	17	0.034 (2.32)
Site	1	5	0	0.474 (3.10)	2	0.065 (3.23)
	2	6	1	0.126 (2.37)	6	0.020 (1.25)
	3	5	0	0.400 (1.59)	1	0.058 (1.94)
	4	5	3	0.073 (2.61)	5	0.020 (1.20)
	5	2	0	0.414 (1.60)	0	0.083 (2.89)
	6	4	0	0.640 (2.01)	3	0.022 (1.69)
Shroud	Rigid	9	0	0.464 (1.96)	6	0.030 (2.14)
	Flexible	8	3	0.139 (3.31)	5	0.031 (1.82)
	Cut	10	1	0.229 (3.30)	6	0.042 (2.97)
Activity	Walls	22	4	0.223 (3.32)	17	0.029 (2.27)
	Ceiling and walls	2	0	0.414 (1.60)	0	0.083 (2.89)
	Columns and walls	3	0	0.410 (1.83)	0	0.060 (1.34)

[a]Number of samples with a respirable crystalline silica mass that was less than the detection limit.

attributed to the small number of samples within a category.

Personal respirable dust and crystalline silica measurements were compared to the 8 h TWA ACGIH TLVs (ACGIH, 2003) and OSHA PELs. Without LEV, the overall geometric mean respirable dust exposure level was 1.60 and 2.66 times the OSHA PEL (5 mg/m^3) and ACGIH TLV (3 mg/m^3), respectively (Table 3). With LEV the average respirable dust exposure level declined to 0.16 and 0.27 times the OSHA PEL and ACGIH TLV, respectively. Similar results were observed with respect to respirable crystalline silica exposures. Without LEV the respirable crystalline exposure levels were a mean of 6.0 and 8.7 times the OSHA PEL and ACGIH TLV (0.05 mg/m^3), respectively. In contrast, the average respirable crystalline silica exposure levels with LEV were 0.71 and 1.14 times the OSHA PEL and ACGIH TLV, respectively.

For respirable dust exposure levels determined during the no LEV treatment, 51.9% of the samples ($n = 27$) exceeded the OSHA PEL and 70.4% exceeded the ACGIH TLV, whereas none of the with LEV treatment samples exceeded the OSHA PEL or ACGIH TLV (Table 3). With respect to respirable crystalline silica exposures, 85% of the samples exceeded both the OSHA PEL and the ACGIH TLV. With LEV, 22% of the samples exceeded the OSHA PEL and 26% of the samples exceeded the ACGIH TLV for respirable crystalline silica.

The overall geometric mean ± GSD task pDR exposure levels with LEV were 0.14 ± 10.5 mg/m^3, which is significantly less ($P < 0.0001$) than the exposure level of 5.46 ± 2.10 mg/m^3 determined without LEV (Table 4). Exposure reduction (equation 2) for the 25 paired samples ranged from 58.9 to 99.9% with an overall arithmetic mean ± SD of 92 ± 9.6%. Mean exposure reduction, by site, ranged from 78 to 97%, with four of the six construction sites exceeding 92%.

With exposure reductions of 94 and 93%, respectively, use of the rigid and flexible shrouds resulted in similar levels of exposure reduction. The cut shroud resulted in a slightly lower exposure reduction of 89%. Exposure reduction levels for wall and wall and column preparation (93% each) are similar. A considerably lower exposure reduction of 81% was observed when ceilings and walls were being prepared.

A linear regression model was developed to determine the effect of different experimental variables on

Table 3. Comparison of respirable dust and quartz exposures to OSHA PELs and ACGIH TLVs ($n = 27$)

	OSHA PEL		ACGIH TLV	
	Fraction of (SD)	Percent greater than	Fraction of (SD)	Percent greater than
Respirable dust				
LEV	0.16 (0.2)	0	0.27 (0.4)	0
No LEV	1.60 (1.5)	51.9	2.66 (2.4)	70.4
Crystalline silica				
LEV	0.71 (0.8)	22.2	1.14 (1.1)	25.9
No LEV	5.95 (5.9)	85.2	8.73 (9.0)	85.2

Table 4. Geometric mean (GSD) for total and task pDR respirable dust exposures (mg/m^3)

Independent variable		n	Total pDR exposure level		Task pDR exposure level		
			No LEV	LEV	No LEV	LEV	Reduction (%)
All data		25	4.95 (2.13)	0.16 (8.60)	5.46 (2.10)	0.14 (10.5)	92 (9.6)
Site	1	3	4.41 (1.79)	0.98 (3.04)	5.64 (2.25)	1.03 (3.25)	78 (16.8)
	2	6	4.45 (1.75)	0.01 (21.8)	5.31 (1.76)	0.01 (23.7)	97 (4.9)
	3	5	7.73 (1.70)	0.38 (1.36)	8.26 (1.72)	0.40 (1.32)	94 (4.4)
	4	5	2.02 (2.21)	0.15 (1.14)	2.25 (2.18)	0.14 (1.12)	92 (5.0)
	5	2	7.97 (1.42)	1.38 (1.86)	8.89 (1.31)	1.37 (1.88)	81 (14.9)
	6	4	8.77 (1.68)	0.19 (1.31)	7.83 (1.64)	0.19 (1.54)	97 (2.4)
Shroud	Rigid	9	8.81 (1.59)	0.10 (15.3)	8.95 (1.52)	0.10 (15.3)	94 (9.2)
	Flexible	8	3.05 (2.37)	0.21 (1.76)	3.40 (2.40)	0.21 (1.76)	93 (4.7)
	Cut	8	4.20 (1.64)	0.14 (22.8)	5.01 (1.77)	0.14 (22.8)	89 (13.2)
Activity	Walls	20	4.58 (2.25)	0.11 (9.51)	5.03 (2.19)	0.09 (11.7)	93 (9.4)
	Ceiling and walls	2	7.97 (1.42)	1.38 (1.86)	8.89 (1.31)	1.37 (1.88)	81 (14.9)
	Columns and walls	3	6.06 (1.60)	0.37 (1.26)	6.78 (1.75)	0.41 (1.13)	93 (5.2)

Table 5. Model describing the effect of site and shroud on exposure reduction

Variable	β (SE)	*P*
Intercept	89.88 (6.91)	<0.0005
Exposure level, no LEV[a]	0.84 (0.55)	0.148
Site (baseline = site 6)		
1	−18.04 (8.40)	0.048
2	2.09 (6.20)	0.741
3	−4.15 (7.91)	0.607
4	−0.69 (9.07)	0.940
5	−15.99 (6.57)	0.027
Shroud (baseline = flexible cut tip shroud)		
Rigid	−0.11 (6.45)	0.987
Flexible	0.85 (7.50)	0.911

[a]Task-based exposure level (mg/m^3) without LEV as measured with a direct reading instrument, variable included in model as a covariate.

the reduction (%) in task-based pDR dust exposures resulting from the use of LEV. The ANOVA model used exposure reduction as the dependent variable and construction site and tool/shroud type as independent variables. To control for the effect of exposure level, task-based pDR dust exposure level without LEV was included as a covariate. The ANOVA model results (Table 5) indicate that the use of LEV results in an exposure reduction of ~90%. The level of reduction achieved was not significantly ($P > 0.05$) different for the shroud configurations used or the initial (no LEV) exposure level. However, there were significant differences ($P < 0.05$, $r = 0.562$) in the level of exposure reduction achieved at the different sites.

DISCUSSION

LEV is an effective control for reducing dust exposures during surface grinding. The use of LEV resulted in the geometric mean respirable dust and respirable crystalline silica exposures being reduced from 0.91 to 0.03 times and from 3.41 to 0.37 times the respective OSHA PELs. With respect to respirable dust exposures only, the use of LEV would not require respiratory protection or any other control measure as none of the personal exposure samples obtained in the LEV treatment was greater than the OSHA PEL or ACGIH TLV. Personal respirable crystalline silica exposures under the LEV treatment were observed to be higher, with 22.2 and 25.9% of the samples exceeding the OSHA PEL and ACGIH TLV, respectively.

These results indicate that, in general, workers will need to use respiratory protection with a protection factor of between 5 and 10 when they are using a hand-held grinder to prepare concrete surfaces. However, without LEV, the worker would need to use a respirator that has a protection factor that is >10, as 15% of the samples were >10 times the OSHA PEL for respirable crystalline silica.

The use of LEV resulted in an overall exposure reduction of 92%. This is comparable with the 95% reduction in respirable dust exposure that was observed in a controlled field study in which LEV was used to control dust during surface grinding (Croteau *et al.*, 2002). Consistency in the exposure reduction observed between the two studies is noteworthy, as the respirable dust exposure levels in the controlled field study, under both the LEV and no LEV treatments, were more than 35 times the dust exposure levels observed in this study. The reasonable level of agreement in exposure reduction between the two studies, despite the large difference in dust exposure levels, suggests that LEV assessment results obtained in a controlled field study may be directly applicable to actual field conditions. Indeed, if this observation is borne out in future studies, controlled field study data could potentially supplant the need to assess LEV efficacy under actual field conditions, which is a considerably more difficult research task.

When examining the results by construction site, four of the six sites are noted to attain an exposure reduction of >92%, despite a 3.7-fold difference in task pDR exposure levels between sites. This is a further indication that the level of exposure reduction achieved is not strongly dependent on the personal respirable dust exposure level.

The lower level of exposure reduction attained at Sites 1 and 5 appears to be a result of the site conditions on the days that monitoring was conducted. At Site 1, a second worker was engaged in surface grinding upwind of the study subject while one of the paired samples was collected. When LEV is not in use, the upstream dust would have a negligible effect on the workers dust exposure, but would substantially increase exposure with LEV in place, compromising the level of dust control attained. In fact, the exposure reduction for this paired sample was only 59%. In addition, the relatively small walls at this site (3 feet high) would increase the amount of time the worker spends preparing the surface along edges. This is an important site condition, as the shroud's seal with the grinding surface is compromised when working on edges, resulting in less effective dust control.

Site 5 was a minimally ventilated, enclosed corridor and, because of the need to maintain work productivity at the site, it was not possible to wait until respirable dust levels were at background concentrations prior to obtaining a LEV treatment sample for one of the paired samples. Consequently, an exposure reduction of only 71% was attained for this paired sample. Observations at Sites 1 and 5, as well as the ANOVA model results which showed that site was a significant predictor of exposure reduction, confirm that the level of dust control achieved when using LEV is dependent on site conditions.

Comparison of the exposure reduction obtained with the three different tool/shroud configurations used is tenuous, as there was minimal crossover of tool use at a given site. The use of different tool types on a given day was minimized in order to maintain productivity and minimize disruptions. With this experimental compromise in mind, the cut shroud was observed to be slightly less effective than the other two shrouds assessed, possibly as a result of dust escaping from the opening at the tip of the cut shroud. However, ANOVA model results indicated that tool/shroud type was not a significant predictor ($P < 0.005$) of exposure reduction. Very few paired samples were obtained while non-wall (ceilings and columns) surfaces were being prepared, so inferences regarding any differences in exposure reduction regarding this parameter cannot be certain. A comparison of different shrouds and other LEV parameters, such as ventilation rate and wall configuration, would best be determined under controlled field conditions using a methodology similar to that used by Croteau *et al*. (2002).

Establishing the efficacy of LEV-equipped hand tools at construction sites is difficult due to the continually changing conditions. This challenge was to a large part overcome through the use of paired samples, multiple sites (six) and a direct reading photometer which was adjusted to remove non-work task-associated exposures. The collection of paired samples, typically within a 1 h time-frame, limited the degree to which conditions might possibly change between implementation of the with and without LEV treatments. Furthermore, it was anticipated that non-task monitoring time could vary considerably between paired samples and, indeed, non-task monitoring time did range from 2.3 to 43.5% of the total monitoring period. Despite the very large degree of variability observed between samples at a particular site, the use of short-term paired samples adjusted to represent actual work task exposure levels resulted in very stable exposure reduction estimates. The monitoring approach used in this study could potentially have applications in other studies assessing engineering control efficacy in situations where field conditions change markedly over the course of a workshift.

The study results, conducted under typical field conditions, demonstrate that LEV is an effective engineering control for reducing respirable crystalline silica exposures during surface grinding. Despite the high level of dust control achieved, 22.2% of the samples collected with LEV in place exceeded the 8 h TWA OSHA PEL for respirable crystalline silica, with the highest individual exposure being 2.5 times the OSHA PEL. Therefore, in the absence of site-specific exposure monitoring data, the use of respiratory protection with a minimum protection factor of five is advised when LEV is used.

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