

Respirable Crystalline Silica Dust Exposure During Concrete Finishing (Grinding) Using Hand-held Grinders in the Construction Industry

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Studies reporting the findings of exposure to crystalline silica dust during concrete finishing in construction settings are scarce due to the dynamic nature of the activity and the existence of many confounding factors. This study was initiated to explore the issue. A total of 49 personal respirable dust samples were collected during concrete finishing while workers used hand-held grinders. Only 15 (31%) of the grinders were equipped with local exhaust ventilation (LEV) systems. The confounding factors (e.g. wind velocity, wind direction, relative humidity and ambient temperature) were determined. To make the sampling task-specific, air sampling was activated only during actual grinding. Task-specific sampling times during each work shift ranged from 10 to 200 min. The concentration of total respirable particulate ranged from 0.34 to 81 mg/m³, with a mean \pm SD of 18.6 \pm 20.4 mg/m³, and the concentration of crystalline silica in the samples ranged from 0.02 to 7.1 mg/m³, with a mean \pm SD of 1.16 \pm 1.36 mg/m³. LEV on the grinders reduced the silica dust level significantly ($P < 0.01$) compared to grinders without LEV. Increased wind velocity also reduced the silica dust concentration significantly ($P < 0.03$). Working upwind reduced the exposure to silica dust compared to working downwind, but the difference was not statistically significant. The time-weighted average concentration of silica dust in 69% of the samples exceeded the current recommended threshold limit value of 0.05 mg/m³, indicating a strong need to devise methods for controlling workers' exposure to crystalline silica dust during concrete finishing activities.

Keywords: concrete finishing; construction; crystalline silica dust; exposure

INTRODUCTION

Each year ~1700000 workers in the USA are exposed to crystalline silica dust by handling flint, quartz, sand and silica powder. More than 100000 workers encounter high risk silica exposure through construction and mining operations (NIOSH, 1991).

Exposure to crystalline silica can result in both respiratory and non-respiratory health effects. Of the respiratory effects, silicosis is one of the most documented occupational diseases (Kane, 1997). Every year, >250 workers in the USA die from silicosis; hundreds more become disabled from this and related diseases such as bronchitis. Goldsmith (1997) highlights a series of links between crystalline silica exposure and other health concerns, including rheuma-

toid arthritis, scleroderma, Sjogern's syndrome, lupus and renal disease. NIOSH (1996) believes further attention should be given to these atypical health effects.

Based on epidemiological studies, crystalline silica dust has been classified as a known human carcinogen (IARC, 1987, 1997). Some reviewers (Goldsmith, 1997; McDonald and Cherry, 1999; Soutar *et al.*, 2000) have questioned whether the available scientific evidence justifies this classification. Most recently, a cohort mortality study of industrial sand workers by Hughes *et al.* (2001) supported a causal relationship between lung cancer and crystalline silica exposure.

Many attempts have been made to collect and discuss existing information on silica dust exposure in the construction industry (Rice *et al.*, 1984; Lofgren, 1993; Rice and Stayner, 1995; Blute *et al.*, 1999). However, exposure levels for specific tasks

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within the construction setting have not been well characterized. Epidemiological studies regarding the construction industry and related exposures are also rare or absent from the literature, primarily because sampling for silica dust in the construction industry presents many problems due to the dynamic environmental conditions and the work practices of the associated individuals.

This study focuses primarily on task-specific (task-based) silica dust exposure assessment defined as 'evaluating personal exposures for the purpose of quantifying workers' exposure to silica dust only during an actual concrete finishing task'. The applications and limitations of this type of exposure assessment in the context of overall exposure assessment have been presented and discussed by others (Stewart and Stenzel, 2000; Susi *et al.*, 2000). Task-specific exposure assessment has been performed on construction sites for lead exposure among ironworkers (Goldberg *et al.*, 1997) and metal fume exposure during welding and thermal cutting (Susi and Schneider, 1995; Susi *et al.*, 2000). To the authors' knowledge, however, no similar studies characterizing silica dust exposure have been published.

The objectives of this study were to: (i) characterize workers' exposure (task-specific and time-weighted average) to total respirable particulate and crystalline silica dust during concrete finishing activities; (ii) examine the influence of a local exhaust ventilation (LEV) system, wind velocity and wind direction on levels of exposure.

MATERIALS AND METHODS

Location and subjects

This study was conducted as part of an Occupational Safety and Health Administration (OSHA) On-site Consultation Service in Ohio and recorded as a specific/limited visit. The study subjects were limited to individuals working within the construction setting performing concrete surface finishing (grinding) as a major part of their responsibilities. Site activity during the research site visits consisted of general concrete work, primarily on building structures (i.e. parking garages, hotels and research buildings). All subjects surveyed were males conducting surface grinding with a 4.5 inch angle grinder while standing. Some grinders were equipped with LEV consisting of a shroud covering the wheel of the grinder and a hose connected to a vacuum system.

Personal and bulk samples

Personal air samples were collected using suction pumps (Gillian Multi-flow Pump; Sensydine, Clearwater, FL) connected to Dorr-Oliver 10 mm nylon cyclones (MSA, Pittsburgh, PA). Each sampling train was calibrated to a recommended flow rate

of 1.7 l/min using an airflow calibrator (DryCal DC-1SC near-frictionless piston calibrator; Bios International, Pompton Plains, NJ). The sampling medium (attached to a cyclone used for capturing respirable silica dust) was a 37 mm, 5.0 μ m pore size PVC filter with a cellulose support pad housed in a two-stage filter cassette. This 10 mm nylon cyclone with its attachments is a light weight, size-selective particulate collector widely recommended by the current methods for sampling airborne respirable crystalline silica (NIOSH, 1998; ACGIH, 2001).

The cyclone and cassette were attached to the shirt collar within the subject's breathing zone with the cyclone inlet orientated in a downward vertical position. After the sampling train was removed from the worker, the post-sampling flow rate was recorded. The post-calibration reading was then checked to ensure that the average value was within 10% of the pre-sampling flow rate value, otherwise the sample was considered invalid.

To perform task-specific sampling, the sampling pumps were set to PAUSE/STOP mode and ran only during actual grinding. If the subject stopped grinding for more than 5 min the pump paused and then resumed when the subject recommenced grinding. To maintain consistent parameters (i.e. wind direction) for a given sample, the sampling medium was changed and a new sample for the new parameter started if the subject's orientation to the wind direction changed. Equipment never changed during a sampling campaign: subjects used a tool (i.e. grinder, respirator, LEV) for the duration of their shift, making the data representative of each situation presented during a sampling campaign.

A bulk (material) sample was submitted for each group of personal air samples to confirm the presence of quartz or cristobalite in the air samples and to assess the presence of other substances (i.e. aluminosilicates, micas, feldspars) that might interfere with the analysis of silica in the air samples. A representative sample of settled dust (rafter) was collected in a 50 ml vial in close proximity to ongoing concrete grinding.

All personal and bulk samples were analyzed in the Wisconsin Occupational Health Laboratory (WOHL) in Madison, Wisconsin, utilizing NIOSH Method 0600 (NIOSH, 1998) to determine the net respirable particulate weight and X-ray diffraction by the WOHL in-house Xray3 method based on NIOSH Method 7500 (NIOSH, 1998) and OSHA ID142 (OSHA, 1995) to determine the levels of crystalline silica dust.

Air (wind) velocity, ambient temperature and relative humidity measurements

During each personal monitoring, air velocity was measured using a thermal anemometer (Alnor CompuFlow model 8525 Thermo Anemometer;

Alnor Instrument Co., Skokie, IL). Wind velocity was tracked throughout the sampling period and the average velocity was recorded. A sling psychrometer (Bacharach Inc., Pittsburgh, PA) was used to record ambient temperature and relative humidity during personal sampling.

Survey data collection

A form was used to document relevant information related to sampling instruments and parameters, subjects' characteristics, work performed and work environment, climatic factors and particulate exposure sampling. If a subject's orientation to the wind direction was observed to be such that the wind blew dust away from the breathing zone, it was recorded as 'upwind', otherwise it was recorded as 'downwind'. The grinder's age, experience and gender were assumed not to affect the results.

Statistical methods

The data for each continuous variable were checked on the assumption of a normal distribution (Kolmogorov–Smirnov test). If the data were not normally distributed, they were transformed into logarithms and the normality test was performed again. If the log-transformed data were not normally distributed, non-parametric statistics were used. Descriptive statistics were used to tabulate mean, standard deviation, median, minimum and maximum and basic exposure information related to each variable. The *t*-test was used to determine differences in the means of two groups (or the Mann–Whitney *U*-test in non-parametric cases). Analysis of variance (the Kruskal–Wallis test in non-parametric cases) was used to check for differences among means of more than two groups. Multiple regression analysis was used to examine the relative effectiveness of control methods in reducing workers' exposure.

RESULTS AND DISCUSSION

Overall, 17 subjects participated in the study; six subjects once each, three subjects twice each, five subjects three times each, two subjects five times each and one subject 12 times. Although some subjects participated repeatedly in the study, each sample reports a distinct workshift. Infrequently, more than one sample was collected in a given shift if the subject's orientation to the wind direction changed.

Multiple regression analysis, used to determine confounding factors, showed that the levels of total respirable particulate and silica dust were not significantly correlated with ambient temperature and relative humidity. Wind velocity (ranging from 0.15 to 4.62 m/s) was categorized into two groups: recordings of >1 m/s were noted as sensible breeze (31%) and recordings of ≤1 m/s were noted as no sensible

breeze (69%). Regression analysis used to check the effects of each of the three variables (LEV, wind velocity and wind direction) on the concentration of dust (while controlling for the other two variables) revealed the following results:

1. The concentration of total respirable particulate was significantly ($P < 0.003$) lower when the grinder was equipped with LEV ($n = 15$) compared with grinders without LEV ($n = 34$). The concentration of respirable silica dust was also significantly ($P < 0.01$) lower when the grinder was equipped with LEV compared with grinders without LEV. The authors are not aware of any published study on the field effectiveness of LEV in concrete polishing grinders. Nonetheless, reports showing the effectiveness of LEV on grinding wheels in fixed locations (Flecher, 1995) and chop saws in the construction industry (Thorpe *et al.*, 1999) indirectly support the findings of this study.
2. The concentration of total respirable particulate was significantly ($P < 0.01$) lower when the wind velocity was >1 m/s ($n = 15$) compared with when the wind velocity was ≤1 m/s ($n = 34$). The concentration of respirable silica dust was also significantly ($P < 0.03$) lower when the wind velocity was >1 m/s compared with when the wind velocity was ≤1 m/s.
3. Concentrations of total respirable particulate and silica dust were lower (but not significantly so) when subjects worked upwind ($n = 10$) compared with concentrations when subjects worked downwind ($n = 39$). Therefore, wind direction was eliminated as an independent variable from further inclusion in data analysis.

When wind velocity was used as a continuous variable: (i) the levels of total respirable particulate (RSP, mg/m³) was significantly correlated with wind velocity (WV, m/s) for grinders using LEV [$\ln(\text{RSP}) = 1.76 - 0.41 \text{ WV}$, $P < 0.03$] and for grinders not using LEV [$\ln(\text{RSP}) = 3.74 - 1.54 \text{ WV}$, $P < 0.001$]; (ii) the levels of silica dust (S, mg/m³) were significantly correlated with wind velocity only for grinders not using LEV [$\ln(\text{S}) = 0.75 - 1.18 \text{ WV}$, $P < 0.001$].

Table 1 provides general information relevant to the study. Tables 2 and 3 summarize personal

Table 1. Task-specific sampling parameters during concrete finishing (flow rate 1.7 l/min, $n = 49$)

Parameter	Mean ± SD	Min–Max	Median
Sampling time (min)	85 ± 51	10–200	73
Wind velocity (m/s)	0.7 ± 0.8	0.2–4.6	0.4
Ambient temperature (°C)	17.2 ± 6.8	1.7–28.7	18.3
Relative humidity (%)	52 ± 15	25–98	48

Table 2. Total respirable particulate exposure (mg/m³) by local exhaust ventilation (LEV) and wind velocity (WV)

LEV	WV (m/s)	Group	<i>n</i>	Mean ± SD	Min–Max	Median
Yes	>1	1 ^a	4	2.32 ± 1.37	0.81–3.70	2.39
	≤1	2	11	6.64 ± 3.73	0.84–12.7	5.57
		Subtotal	15	5.49 ± 3.40	0.81–12.7	4.68
No	>1	3	11	9.52 ± 11.7	0.34–40.0	4.60
	≤1	4	23	31.4 ± 22.5	3.80–81.0	27.0
		Subtotal	34	24.3 ± 16.6	0.34–81.0	18.6
Total			49	18.6 ± 20.4	0.34–81.0	9.92

^aSignificant differences between groups 1 and 2 ($P < 0.04$), 1 and 4 ($P < 0.01$), 2 and 4 ($P < 0.001$) and 3 and 4 ($P < 0.001$).

Table 3. Respirable silica dust exposure (mg/m³) by local exhaust ventilation (LEV) and wind velocity (WV)

LEV	WV (m/s)	Group	<i>n</i>	Mean ± SD	Min–Max	Median
Yes	>1	1 ^a	4	0.26 ± 0.33	0.04–0.75	0.13
	≤1	2	11	0.43 ± 0.28	0.03–1.00	0.43
		Subtotal	15	0.38 ± 0.29	0.03–1.00	0.39
No	>1	3	11	0.61 ± 0.50	0.02–1.80	0.47
	≤1	4	23	1.93 ± 1.64	0.17–7.10	1.56
		Subtotal	34	1.50 ± 1.50	0.02–7.10	0.92
Total			49	1.16 ± 1.36	0.02–7.10	0.67

^aSignificant differences between groups 1 and 4 ($P < 0.01$), 2 and 4 ($P < 0.001$) and 3 and 4 ($P < 0.01$).

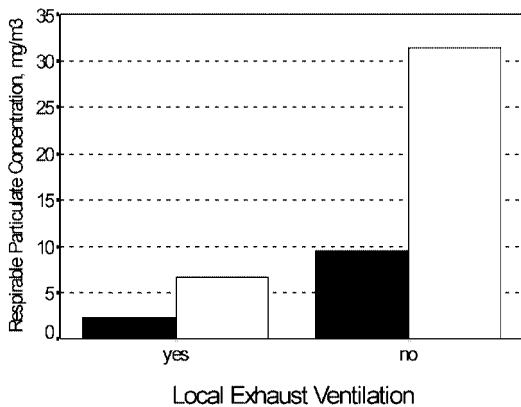


Fig. 1. Concentrations of total respirable particulate by the existence of LEV and sensible wind velocity. Wind velocity >1 m/s (filled boxes) or ≤1 m/s (empty boxes).

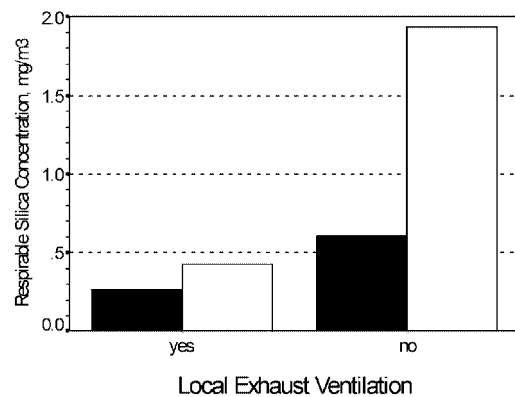


Fig. 2. Concentrations of respirable silica dust by the existence of LEV and sensible wind velocity. Wind velocity >1 m/s (filled boxes) or ≤1 m/s (empty boxes).

exposure to total respirable particulate and to silica dust by the existence of LEV and the influence of wind velocity. Figures 1 and 2 depict the levels of breathing zone dust in relation to the existence of LEV and sensible wind velocity.

To determine the extent of overexposure to silica dust, an 8 h time-weighted average (TWA) exposure was calculated, conservatively assuming that occupational exposure to dust equaled 0 for time not sampled (no grinding occurring). The resulting 8 h TWA was then divided by the permissible exposure limit (PEL) mandated by OSHA, as calculated by

the equation $PEL = [10 \text{ mg/m}^3 / (\% \text{ silica} + 2)]$, and the threshold limit value (TLV) of 0.05 mg/m³ recommended by the American Conference of Governmental Industrial Hygienists (ACGIH, 2001), respectively. This generated a ratio of TWA concentration to the respective occupational exposure limit (Table 4). An overexposure was established when this ratio, termed the 'exposure severity factor', exceeded unity.

Using the OSHA PEL as the criterion, 31% of subjects were overexposed to crystalline silica dust, with 2% exposed to ≥5 times the PEL. This confirms

Table 4. Frequency of respirable silica dust exposure severity factor (ESF) by local exhaust ventilation (LEV) and wind velocity (WV)

LEV	WV (m/s)	n	OSHA PEL ESF			ACGIH TLV ESF		
			<1	1-4	≥5	<1	1-4	≥5
Yes	>1	4	3	1	0	4	0	0
	≤1	11	11	0	0	3	8	0
	Subtotal	15	14	1	0	7	8	0
No	>1	11	9	2	0	5	5	1
	≤1	23	11	11	1	3	8	12
	Subtotal	34	20	13	1	8	13	13
Total		49	34	14	1	15	21	13

OSHA, Occupational Safety and Health Administration; PEL, permissible exposure limit; ACGIH, American Conference of Governmental Industrial Hygienists; TLV, threshold limit value.

the findings of others: K.D.Linch (NIOSH), examining 65 silica samples taken between 1980 and 1995, found that 34% of these samples exceeded the OSHA PEL; Blute *et al.* (1999), evaluating 77 respirable dust samples, indicated that concrete work was the primary source of silica exposure on the project site. They reported that construction employees had the highest exposures compared to other trades. Using the ACGIH TLV as the criterion, 69% of these subjects were overexposed to crystalline silica dust, with 27% exposed to ≥5 times the TLV.

All but two of the subjects in our study wore a half-mask respirator. The high percentage (96%) of these subjects using a respirator, as well as the researchers' field observations, confirm that the two companies participating in this study, unlike the construction industry as a whole, had developed and implemented a fairly advanced health and safety program which included a respiratory protection component.

The protection factor of the half-face respirators used during this study is often assumed to be 10 (NIOSH, 1987; Revoir and Bien, 1997). Using the OSHA PEL, none of the subjects were overexposed to crystalline silica dust while wearing this type of respirator. Using the ACGIH TLV, 2% of these subjects were overexposed to crystalline silica dust even when wearing a half-mask respirator.

CONCLUSIONS

1. Approximately 69% of subjects performing concrete grinding were overexposed to respirable crystalline silica dust.
2. Levels of exposure to respirable crystalline silica dust were significantly lower when subjects used a grinder equipped with LEV as compared to exposure levels of subjects using a grinder without LEV.
3. Levels of exposure to respirable crystalline silica dust were significantly lower when wind velocity

was sensible compared to exposure levels when wind velocity was not sensible.

RECOMMENDATIONS

1. Studies of sampling methodologies and data interpretation for concrete grinding and other high risk tasks should be continued.
2. This study should be extended to address employees' residual exposure to respirable crystalline silica dust on sites where concrete finishing is performed but subjects are not actually conducting the task.
3. Control methods (LEV and respirators) should be improved and combined with administrative controls (reducing exposure time and employing sound work practices such as working upwind and using wet methods) to reduce silica dust exposure to acceptable levels.

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