Applied Occupational and Environmental Hygiene
Volume 18(4): 268–277, 2003

1047-322X/03 $12.00 + .00
DOI: 10.1080/10473220390115084

Engineering Controls for Selected Silica and Dust Exposures in the Construction Industry — A Review

Michael R. Flynn[1] and Pam Susi[2]
[1]*Department of Environmental Sciences and Engineering, University of North Carolina at Chapel Hill, Chapel Hill, North Carolina;* [2]*Center to Protect Workers' Rights, Silver Spring, Maryland*

This literature review summarizes engineering control technology research for dust and silica exposures associated with selected tasks in the construction industry. Exposure to crystalline silica can cause silicosis and lung fibrosis, and evidence now links it with lung cancer. Of over 30 references identified and reviewed, 16 were particularly significant in providing data and analyses capable of documenting the efficacy of various engineering controls. These reports include information on generation rates and worker exposures to silica and dust during four different tasks: cutting brick and concrete block, grinding mortar from between bricks, drilling, and grinding concrete surfaces. The major controls are wet methods and local exhaust ventilation. The studies suggest that while the methods provide substantial exposure reductions, they may not reduce levels below the current ACGIH® threshold limit value (TLV®) of 0.05 mg/m^3 for respirable quartz. Although further research on controls for these operations is indicated, it is clear that effective methods exist for significant exposure reduction.

Keywords Silica Exposure, Engineering Controls, Construction Industry

Inhalation of crystalline silica as quartz, cristobalite, or trydimite has long been associated with lung disease including silicosis, progressive massive fibrosis, and, more recently, lung cancer.(1) The 2002 American Conference of Governmental Industrial Hygienists (ACGIH®) threshold limit value (TLV®) booklet(2) lists the respirable time-weighted average (TWA)-TLV for each of the three forms of crystalline silica as 0.05 mg/m^3 with an A2 notation for quartz, indicating it as a potential human carcinogen. The National Institute for Occupational Safety and Health (NIOSH) recommended exposure level (REL) for respirable quartz is 0.05 mg/m^3 as an 8 hr TWA, and it is also considered a potential human carcinogen.(3) The Occupational Safety and Health Administration (OSHA) permissible exposure limit (PEL) for respirable quartz in the construction industry is given in CFR 1926.55 as a formula for the 8 hr TWA in mppcf, (millions of particles per cubic foot) based on impinger sampling. However, the formula in the general industry standards CFR 1910.1000 Table Z-3 based on cyclone sampling is used more commonly for respirable dust, where a specific standard for each dust is calculated based on its silica content.(4)

A recent survey(5) of OSHA compliance data states:

> some of the highest respirable crystalline dust concentrations occurred in construction (masonry, heavy construction and painting) and in metal services. . . . It was found that 1.8 percent (13,800 workers) of those employed in SIC 174—Masonry, Stonework, Tile Setting and Plastering—were exposed to at least 10 times the NIOSH REL.

The study concludes, "Not enough is being done to control exposure to respirable crystalline silica. Engineering controls should be instituted in the industries indicated by this work." Recent articles(6–8) have shown that significant exposures to airborne dust and silica in the construction industry are associated with many different tasks. Some of these are cutting brick and concrete block, drilling, surface grinding of concrete floors and walls, and the removal of mortar between brick and other masonry units prior to re-pointing operations.

Successful local exhaust ventilation (LEV) controls for silica exposure generated during stone and granite work have been documented as early as the 1930s(9) for a variety of applications. A number of more recent and generic studies(10–13) for evaluating local exhaust hoods for grinding operations may provide useful information for systems applicable to construction jobs. In the material that follows the specific tasks of removing mortar from between bricks, surface grinding of concrete, the cutting of concrete block, and the drilling of silica-containing materials are examined. Recent literature presenting information pertinent to the control of silica from these operations is summarized. Given the increased information on the health hazards of crystalline silica, including its potential carcinogenicity, and the TLV reduction for quartz that occurred in 2000, it would seem that additional research is now needed to achieve successful engineering control of these exposures.

MORTAR REMOVAL PRIOR TO RE-POINTING

As existing masonry structures age, renovation projects involving the repair of masonry units such as brick, concrete block, and stone have become increasingly important. The deteriorating mortar between the masonry units is removed, generally with a handheld angle grinder, in a careful fashion so as not to damage the existing brick, prior to re-pointing. This removal operation generates a significant amount of silica-containing dust and control measures appear to have been less than completely successful as the following research indicates. Figures 1a and 1b show, respectively, an unventilated and ventilated electric angle grinder being used to remove mortar prior to a re-pointing operation. The dust cloud is clearly visible in the unventilated case. Figures 2a and 2b show a close-up view of the moveable shroud of this particular local exhaust system.

Several studies[14–18] reported field measurements of worker exposure during these types of grinding operations. The first[14] involved respirable silica exposures on workers using grinders to remove old mortar during a renovation. Ten personal samples on uncontrolled grinding produced respirable silica exposures ranging from 1.29 to 2.8 mg/m^3 with respirable dust ranging from 5.4 to 16.9 mg/m^3, total dust exposures ranged from 24.4 to 442.0 mg/m^3; all samples exceeded 500 minutes in duration. A ventilated Metabo grinder produced a personal respirable quartz exposure of 9.01 mg/m^3 for a 30-minute sample. A wet method used in conjunction with a local exhaust (estimated at 140 cfm) seemed to provide some protection. For a one-hour personal sample total and respirable dust concentrations were reported at 0.59 and 0.38 mg/m^3 and relative real-time dust concentration measurements suggested a protective effect as well.

Questions were raised regarding the electrical shock hazard with water-based methods and the authors noted that the use of pneumatic grinders might be a viable option. Observations on work practices and their effect on exposure were made by the workers, suggesting that it is important that the control does not obscure visibility—otherwise the bricks are damaged. In addition, the tool needs to be flush on the wall or else there is leakage of dust, back and forth movement of the tool can cause leakage, and the air cleaning bag may leak dust.

In a second, similar field study to remove mortar from between bricks,[15] the grinders were ventilated but apparently at an insufficient flow and dust was discharged back into the workplace. The mean exposure to respirable dust for four workers was 20.99 mg/m^3 with a standard deviation of 14 mg/m^3. The corresponding respirable silica exposures had a mean of 2.94 mg/m^3 with a standard deviation of 1.68 and ranged from 0.1–4.5 mg/m^3. The pressure drop through the system was implicated as being too great for the fan's capacity. This study cites a recommendation for 120 cfm per shroud for ventilating 4 inch angle grinders used to remove mortar from between bricks. The reference given is *Dust Control Handbook for Planning and Dimensioning Spot Extraction* (Gunnar Soderberg, ed. Norsborg, Sweden [1987]).

(*a*)

(*b*)

FIGURE 1
Removal of mortar prior to re-pointing with electric angle grinder: (a) unventilated unit with dust cloud; (b) ventilated unit.

A Master's thesis[16] involved a controlled field experiment examining several different silica exposure scenarios including sawing brick and concrete block, grinding mortar from between brick, and surface grinding. This work presents one of the more careful and useful data sets available for evaluating controls. Measurements of ventilation rates, dust emission rates, and exposures are presented and a careful statistical analysis was conducted. The experiments were conducted in reasonably

(*a*)

(*b*)

FIGURE 2
Close-up views of the local exhaust hood on the angle grinder: (a) working position against the wall; (b) moveable hood showing exposed grinding wheel.

TABLE I
Summary exposure data for mortar removal using an angle grinder (prior to re-pointing)[A]

Control	Geometric mean, respirable dust (mg/m^3)	G.S.D., respirable dust	Geometric mean, respirable quartz (mg/m^3)	G.S.D., respirable quartz
No vent N = 14	22.17	2.42	3.04	1.98
Low vent (30 cfm) N = 14	6.11	1.85	1.02	1.76
High vent (70 cfm) N = 13	3.01	3.31	0.47	3.27

[A]Data taken from Croteau (2000).[16]

well-controlled environments to correct for confounding conditions; for example, cross drafts, silica content of the materials, and differing work rates. An angle grinder (Flex Model F1509 FR) was used to remove mortar prior to tuck pointing. A summary of the results applicable to angle grinding is presented in Table I. In subsequent sections additional data from this work are also reported.

A fourth field study[17] showed reductions in personal exposure to silica generated during grinding operations prior to tuck pointing. The exposures are reported with and without controls and there was an effort made to adapt the controls to the grinders in such a way as to improve the feasibility of their use. Without local exhaust ventilation respirable silica exposures were reported as 4.08 mg/m^3, with the modified controls 0.306 mg/m^3 was reported. The corresponding values without and with ventilation for respirable dust were 94.6 and 2.97 mg/m^3. The study contains some additional data on silica exposures and control effectiveness; the numbers cited here represent the "optimal" solution based on improving the equipment design. The authors suggest that this was the first time exposures were reduced to less than 10 times the PEL thus permitting the use of negative pressure, air-purifying, half-masks.

The final field study[18] cited here reported respirable dust and silica exposures for bricklayers and apprentices involved in mortar removal between bricks at a college dormitory prior to re-pointing. The workers used handheld electric grinders with 4.5 inch diameter, 1/4-inch-wide diamond wheels. The grinders were equipped with a local exhaust system, which was essentially a plastic shroud enclosing about 80 percent of the wheel, exhausted by an impeller driven by the grinder motor. Dust was transported by a 1.5 inch diameter hose to a fabric filtration bag.

The authors collected detailed observations on work practices and identified factors leading to increased visible dust emission including: side-to-side movement of the grinder, grinding with open spaces ahead of the wheel, and exerting excessive force on the wheel, among others. The authors reported 11 of 17 monitored employees exceeding the OSHA PEL for respirable dust containing silica.

Respirable silica exposures ranged from 6.9 mg/m^3 to non-detected, and the corresponding respirable dust exposures were from 49.32 to 0.106 mg/m^3. The capture efficiency of the ventilated shroud and the filtration efficiency of the filter bag for respirable particles were implicated as being inadequate to provide the needed engineering control.

In addition to the fieldwork, a significant laboratory study[19] was conducted in a ventilated enclosure relating dust generation to the amount of mortar removed for locally ventilated and unventilated grinding tools used prior to tuck-pointing operations. Similar measurements were made for dry brick cutting. The authors reported a generation rate of 20 mg of respirable dust per cubic centimeter of mortar removed during the grinding when there was no local exhaust ventilation. For a 4-inch grinding wheel 80 cfm was the minimum local exhaust flow that reduced respirable emissions below 0.2 mg/cc of mortar removed. A router (mortar rake) was successful in accomplishing the same level of dust generation with 35 cfm of local exhaust flow. Further increases in flow did not seem to produce any additional effect. Figures in the report suggested that the minimum asymptotic dust generation rates (based on maximal local exhaust flows) for the router approached 0.01 mg/cc whereas the grinders had asymptotic rates an order of magnitude higher at about 0.1 mg/cc. The authors observed increased dust emissions when grinders were moved in reverse directions. Figure 3 shows a picture of a ventilated mortar rake being used in a field study.

The authors concluded that the 4-inch grinder required 20 cfm/inch of blade or wheel diameter to control emissions

FIGURE 3
Ventilated mortar rake in operation.

TABLE II
Side by side area sample results from surface grinding on concrete walls ($N = 4$)[A]

Control	Mean, respirable dust (mg/m^3)	SD, respirable dust	Mean, respirable silica (mg/m^3)	SD, respirable silica
No controls	3.09	0.09	0.18	0.06
Wet grinding	0.04	0.01	0.02	0.00
Mini Vac	0.54	0.03	0.05	0.00
Maxi Vac	0.53	0.05	0.04	0.00
WAP	0.10	0.00	0.05	0.00

[A]Data taken from NIOSH (1998).[20]

and noted the agreement with the *ACGIH Ventilation Manual* recommendation of 25 cfm/inch. (Note: the author's reference VS-40-01 to 03, which are probably the closest VS plates to the operation in question). The authors noted the need for field validations, as the mechanical tests would not be representative of actual operations. They recommended further investigation of the mortar rake as a control device, suggesting it may "fare better in field tests than the 4.5 inch grinders." The study did not contain any personal exposure measurements.

SURFACE GRINDING OPERATIONS

In addition to the mortar-removal grinding operations, a significant exposure may also occur during surface grinding and smoothing of concrete walls and floors. One study[20] looked at respirable dust and respirable silica exposures to workers smoothing concrete walls with electric handheld angle grinders using 4-inch discs. Three commercial local exhaust systems and wet methods were evaluated as controls. No-control conditions were also reported. Wet methods and local exhaust provided substantial reductions in exposures relative to the no-control cases. The data include both area and personal samples and are summarized in Tables II and III, respectively.

A second field study[21] reported exposures during the surface grinding of concrete walls and columns for a sports stadium. The workers used 5-inch-diameter grinders, and full-shift sampling indicated mean exposures ($N = 7$) to respirable silica of 0.25 mg/m^3 and for respirable dust a mean of 2.24 mg/m^3. The workers were also involved in some concrete coring (drilling) work during the sampling period. Local exhaust hoods were not used and the reasons reported included slowed productivity and the shrouds on the hoods made it difficult to get into corners.

In addition to the angle grinding work reported above, Croteau also conducted a study with surface grinders; the data are reported in Table IV. A Flex Model LD 1509 FR flat grinder was used during surface grinding on concrete walls. A recent paper[22] reported 49 personal respirable silica samples taken on grinders polishing concrete in the standing position. The sampling was done only during grinding activities and with a median duration of 73 minutes. The concentration of respirable particulate ranged from 0.3–81.0 mg/m^3 and the concentration of silica ranged from 0.02 to 7.1 mg/m^3. Fifteen of the grinders were equipped with local exhaust (flow rates were not specified) and these operators had a mean silica exposure of 0.38 mg/m^3 compared with an exposure of 1.5 mg/m^3 for those who did not. The authors noted a protective effect of the ambient wind direction on blowing dust out of the operators breathing zone.

Information downloaded from a website[23] reported on silica exposures generated during the surface grinding of concrete sidewalks. Comparisons are made between the no-control case and the use of a Sawtek Mini Vac for a 7-inch surface grinder. The no-control respirable silica exposure with the aluminum cyclone is 11.71 mg/m^3; with the Mini Vac and 6 ft of hose the level was 0.48 mg/m^3; and with the Mini Vac and 25 ft of hose the level was 0.4 mg/m^3. A flow rate for the Mini Vac was not reported but a static pressure of 0.2 in of water was measured at the "grinder end of the hose."

CUTTING AND SAWING OPERATIONS

Perhaps one of the most challenging operations to control is the cutting of concrete block and brick material. The saws used to do this appear to be particular offenders, especially the portable masonry saw. Figure 4 shows the type of dust cloud generated when the portable masonry saw (chop saw) is used to cut a concrete block. Wet methods appear essential in achieving control and several recent studies are pertinent. Figure 5 shows a stationary masonry saw with water application to suppress dust.

TABLE III
Personal sample from surface grinding on concrete ($N = 1$)[A]

Control	Respirable dust (mg/m^3)	Respirable silica (mg/m^3)	Sample time (min)
No controls	10.69	0.66	191
Wet grinding	0.36	0.02	225
Mini Vac	n.d.	n.d.	127
Maxi Vac	1.45	0.13	150
WAP	0.30	n.d.	117

[A]Data taken from NIOSH (1998).[20]
Note: WAP is the name of a German-made shop-vacuum cleaner; The Mini Vac and Maxi Vac are Sawtek products.

TABLE IV
Summary exposure data for surface grinding[A]

Control	Geometric mean, respirable dust (mg/m^3)	G.S.D., respirable dust	Geometric mean, respirable quartz (mg/m^3)	G.S.D., respirable quartz
No vent N = 5	165.34	1.24	29.16	1.24
Low vent (30 cfm) N = 6	11.15	1.72	2.36	1.72
High vent (70 cfm) N = 5	8.00	1.35	1.70	1.34

[A]Data taken from Croteau (2000).[16]

A lab and field study[24] of dust suppression systems for cut-off saws in the construction industry noted on-site reductions of from 3–7 times for both wet methods and local exhaust ventilation (LEV). The diameters of the saw blades were 9 and 12 inches and both diamond and resin-glass fiber type blades were used. Respirable dust levels were reduced by at least 90 percent for either wet methods or LEV. A diamond blade wheel cut faster than a resin bonded wheel and that was significant in accomplishing the cutting before water reservoir pressure was depleted. Emphasis on maintaining pressure supply in water reservoirs was reported. Laboratory studies of dust concentrations generated during controlled cutting indicated that increasing water flow rates were directly correlated with dust reductions. A water flow rate of at least 0.5 liter per minute was recommended.

In his thesis Croteau[16] also looked at controls for respirable dust exposures on both fixed and handheld masonry saws. A gasoline powered EDCO GMS-10 fixed masonry saw was used to cut paver blocks and bricks. This saw was reported to have a diamond blade with a diameter of 24 cm and operate at 5500 rpm. The handheld, gasoline-powered, Partner Model K650 Active saw was used for cutting concrete blocks. It had a 30.5 cm diameter diamond blade and ran at 3600 rpm. Three levels of local exhaust were examined: none, low (29.4 cfm), and high (74.2 cfm). Statistically significant ($p < 0.05$) exposure reductions were reported for all cases except the handheld saw, although reductions below the TLV of 0.05 mg/m^3 were not obtained for respirable quartz. The operator of the handheld saw had respirable dust levels of 2.4 mg/m^3 both with and without ventilation. Wet methods were not investigated. Table V presents the results for the masonry saw.

One study[23] looked at a fixed masonry saw in a partially enclosed booth-type hood ventilated at approximately 930 cfm.

FIGURE 4
Dust cloud generated during the dry cutting of concrete block using a portable masonry saw.

FIGURE 5
Wet cutting of concrete using a stationary masonry saw.

Personal exposure samples for respirable silica were made during a 30-minute period for various cutting activities. The results showed for no-control (dry cutting in the open with no ventilation) the concentration was 5.03 mg/m^3. With ventilation this was reduced to 0.74 mg/m^3. The study noted that filter bags in the ventilation system became saturated with dust quickly and in general the ventilation design was not particularly good.

Another paper(26) examined indoor silica exposure during wet-cutting operations that included concrete coring, wall sawing, and slab sawing. The mean exposure for the 5 workers cutting slabs was 0.31 mg/m^3; the mean for the wall saw operators was 0.13 mg/m^3; and the corers had a mean exposure of 0.02 mg/m^3. Two of the slab saws had water flow rates of 0.5 gallons per minute (GPM) and the operators mean exposure was 0.33 mg/m^3 while one saw operated at a water flow of 2.0 GPM and the exposure was 0.11 mg/m^3. Although not specifically stated it appears all measurements were respirable.

NIOSH investigators(19) examined dust generation rates in a laboratory experiment for a 10-inch stationary masonry saw. When there was no local exhaust ventilation, the respirable dust concentration in the extract tunnel was 13 mg/m^3. When 93 cfm was exhausted below the brick and 113 cfm exhausted from the blade guard the extract tunnel respirable concentration dropped to 0.05 mg/m^3. They concluded 20 cfm/inch of blade was needed to control emissions. In a series of field studies(27–30) NIOSH investigators also documented high exposures associated with dry cutting of concrete and masonry units and showed lower exposures when wet methods were used.

TABLE V
Summary exposure data for paver block cutting with masonry saw[A]

Control	Geometric mean, respirable dust (mg/m^3)	G.S.D., respirable dust	Geometric mean, respirable quartz (mg/m^3)	G.S.D., respirable quartz
No vent N = 6	89.85	1.42	22.52	1.48
Low vent (30 cfm) N = 6	13.12	1.44	3.32	1.44
High vent (70 cfm) N = 6	4.31	1.48	0.95	1.44

[A]Data taken from Croteau (2000).(16)

TABLE VI
Personal sampling results from highway construction[A]

Machine type	Mean, respirable dust (mg/m^3)	Range, respirable dust	Mean, respirable quartz (mg/m^3)	Range, respirable quartz
Chipping gun	1.74 n = 10	0.29–10.27	0.28 n = 10	0.009–1.64
Drill	4.23 n = 12	0.36–21.77	0.43 n = 10	0.05–1.49
Grinder	3.09 n = 7	0.17–9.78	0.014 n = 3	0.008–0.27
Concrete mixer	1.81 n = 11	0.19–7.51	0.010 n = 3	0.009–0.013
Scabbler	0.36 n = 4	0.18–0.49	0.049 n = 3	0.01–0.079

[A]Data taken from Bulte et al. (1999).[(34)]

DRILLING AND MISCELLANEOUS OPERATIONS

In addition to the jobs identified above there are many other construction tasks that result in silica exposure, including drilling, concrete mixing, and cleanup, just to name a few. NIOSH investigators[(31)] sampled rock drilling operations at a quarry that supplied material to an aggregate plant. An Atlas Copco ROC 748HC drill that was tractor driven and capable of drilling at 3 fpm was used. The drill was equipped with a water spray at the rock-bit interface that could deliver between 10 and 100 gallons per day. A local exhaust hood and air cleaner were also used to draw air and debris through the drill hole. A 5-inch flexible duct exhausted at 300 cfm. In addition, enclosed cabs were provided for vehicles although the investigators noted that the workers often opened the windows on the cabs during the day. All exposures reported (N = 5) were below the TLV of 0.05 mg/m^3 for respirable silica.

Flanagan[(32)] reported on silica exposures during concrete drilling operations at a bridge renovation project (handheld and caddy-held drills were used). Some patching work involving masons doing grinding and chipping and filling were also sampled. Personal and area monitoring results were reported. The driller's TWA exposures to respirable silica were 0.09 and 0.08 mg/m^3. The masons had exposures of 0.08 and 0.03 mg/m^3. The caddy-held drill (E-Z Drill) apparently produced lower exposures. The author used both aluminum and nylon cyclones; the results reported here are with the nylon cyclone at 1.7 Lpm.

A recent study[(33)] described and quantified dust reductions associated with blowing clean air into the breathing zone. Chipping hammers, concrete breakers, and angle grinding tools were examined in the field and real-time dust concentrations with blowing air on and off were compared. Reductions were evident over times less than 20 minutes, but issues related to maintaining a clean air supply and also polluting adjacent areas were raised. The equipment used was essentially a portable fan with flexible duct connected to a honeycomb, or punched board diffuser. The air flowed out of the diffuser and was directed at the operation.

In another field study[(34)] personal exposure measurements on workers involved in highway construction were collected. There were few controls apparently in use and some observations were made on the use of a fan to blow dust away from the breathing zone of a laborer mixing concrete. The investigators collected impactor samples, first an area sample 8 ft downwind of the fan and then a personal sample. The personal respirable dust measurement was reported as 6.17 mg/m^3 while the area was 0.91 mg/m^3. The authors stated that since the personal sample had 13 percent of its mass below 3.5 microns while the area sample had 30 percent of its mass below this cutoff, the fan "may have had an impact on reducing the operators exposure to respirable sized particles." Some of the other exposure data are presented in Table VI.

Riala[(35)] reported exposures to dust and quartz in construction cleaners. Mean total dust during dry sweeping was measured at 32 mg/m^3 with a mean respirable quartz level of 0.53 mg/m^3. Renovations were dustier than newer facilities, and vacuuming was better than dry sweeping for minimizing exposures. There were apparently no measurements made using wet methods or ventilation controls. Another study[(36)] suggested the use of a central vacuum system as a control measure for construction renovation sites. Issues such as ergonomics, noise, dust levels, and economic feasibility are discussed. Real-time dust levels in the breathing zone are presented for various operations. The work is not necessarily specific to construction and silica exposures.

CONCLUSIONS

Worker exposure to crystalline silica and dust remains a challenging control problem in many construction jobs, including the operations reviewed here. Although studies of these exposures have been reported, relatively few contain the comprehensive information needed to document effective engineering controls. In particular, quantitative information on ventilation and/or water flow rates, dust generation rates (or a suitable surrogate), and work practices are often lacking. Several studies reviewed here, however, did provide very useful information as shown in Tables I–VI, and the results are summarized by job below. Although further laboratory and field studies are needed to document optimal control solutions for these and other dust-generating tasks in the construction industry, it is clear that technology is currently available to provide dramatic reductions in exposure.

Mortar Removal Prior to Re-Pointing

The successful use of local exhaust ventilation on handheld grinders and routers used during mortar removal prior to tuck pointing operations requires further study. Results to date suggest that ventilating the enclosing shroud at a rate of 20–25 cfm per inch of wheel or blade diameter is required to minimize dust generation. While these methods are important in providing substantial reductions in exposure, they may not reduce levels below the NIOSH REL and ACGIH TLV of 0.05 mg/m^3 for respirable silica. It is unclear whether the addition of wet methods will accomplish this either although some promising results are noted. Part of the problem appears to be work practices used during the job, particularly moving the grinder back and forth, and not maintaining the shroud flush to the wall.

The success of local exhaust ventilation for this operation will also depend upon well-designed systems that include adequate air cleaners. Provisions for regular cleaning of the air filters must also be made to avoid degradation of ventilation flows, perhaps a pressure drop alarm similar to spray booths should be considered. Leakage of air into the system will short-circuit the flow to the hood and care must be taken to maintain system integrity. A fan of sufficient capacity is needed to maintain adequate transport velocity and avoid settling and the resulting loss of air flow to the hood. The development of tools to remove the mortar in larger chunks and produce less respirable dust should also be considered. The mortar rake (router) appears to be a step in this direction.

Surface Grinding Operations

Exposures to dust and silica during surface grinding of concrete are reduced with both local exhaust ventilation and with wet methods. However, few of the studies provided adequate detail to come to definitive conclusions, and further studies are needed to document the required air flow rates for the hoods.

Cutting and Sawing Operations

The use of wet methods and local exhaust ventilation provide significant reductions in exposures for cutting operations using either fixed or handheld masonry saws. Water flow rates to the saw are directly correlated with dust reductions; a flow rate of 0.5 gallons per minute seems to be the indicated minimum. Maintaining this flow rate over time is critical to successful control, and adequate pressure is needed in the water delivery system to achieve this stability. Several different local exhaust configurations are promising including simultaneous exhaust from the blade guard, and below the material being cut. An air flow rate of 20 cfm per inch of saw blade has been suggested.

ACKNOWLEDGMENTS

This work was conducted through a cooperative agreement between NIOSH and CPWR (grant no. U60/CCU317202). The authors wish to thank those whose work formed the foundation for much of this review, especially Mary Ellen Flanagan, William Heitbrink, Alan Echt, George Weymouth, and Barry Cardwell. The authors also acknowledge the assistance of the unions affiliated with the Building and Construction Trades Department, AFL-CIO, particularly the International Union of Bricklayers and Allied Craftworkers.

REFERENCES

1. Borm, P.J.A.; Donaldson, K.: The Quartz Hazard in the Construction Industry, Indoor Built Environ 8:107–112 (1999).
2. American Conference of Governmental Industrial Hygienists: 2002 TLVs and BEIs Threshold Limit Values for Chemical Substances and Physical Agents and Biological Exposure Indices. ACGIH, Cincinnati, OH (2002).
3. National Institute of Occupational Safety and Health: NIOSH Pocket Guide to Chemical Hazards and Other Databases, NIOSH Publication 2001-145. NIOSH Cincinnati, OH (2001).
4. Occupational Safety and Health Administration: Code of Federal Regulations—Part 29 CFR 1910.1000 Table Z-3. U.S. Government Printing Office, Washington, DC (1999).
5. Linch, K.D.; Miller, W.E.; Althouse, R.B.; Groce, D.; Hale, J.: Surveillance of Respirable Crystalline Silica Dust Exposure Using OSHA Compliance Data (1979–1995). Am J Indus Med 34:547–558 (1998).
6. Lofgren, D.J.: Silica Exposure for Concrete Workers and Masons. Appl Occup Environ Hyg 8(10):832–836 (1993).
7. Galster, C.: A Significant Workplace Exposure to Crystalline Silica. Appl Occup Environ Hyg 12(8):522–523 (1997).
8. Chisolm, J.: Respirable Dust and Respirable Silica Concentrations from Construction Activities. Indoor Built Environ 8:94–106 (1999).
9. Urban, E.C.J.: Ventilation in the Granite Industry. J Indus Hyg Tox 21(3):57–66 (1939).
10. Olander, L.; Krantz, S.: A Method of Evaluating the Capture Efficiency of a Local Exhaust System. National Board of Occupational Safety and Health, Scientific Publication Series Entitled Work and Health. Stockholm (1976).
11. Jansson, A.: Capture Efficiencies of Local Exhausts for Hand Grinding, Drilling and Welding. Staub-Reinhalt. Luft. March 3. (1980).
12. Tapola, M.H.: Test Method for Local Exhaust Hoods for Hand Tools. In: *Vent 88*, J.H. Vincent, ed. Pergamon Press, Oxford, England (1988).
13. NIOSH: Ventilation Requirements for Grinding, Buffing, and Polishing Operations. Research Report HEW Publication Number (NIOSH) 75-107. NIOSH, Cincinnati, OH (1975).
14. Heitbrink, W.A.: In-Depth Study Report: Control Technology for Crystalline Silica Exposures in Construction: Exposures and Preliminary Control Evaluation. Report # ECTB NO 247-12. NIOSH, Cincinnati, OH (2000).
15. Heitbrink, W.A.: In-Depth Study Report: Control Technology for Crystalline Silica Exposures in Construction: Exposures and Preliminary Control Evaluation at a Restoration Preservation Masonry Construction Site. Report # ECTB NO 247-14. NIOSH, Cincinnati, OH (2000).
16. Croteau, G.: The Effects of Local Exhaust Ventilation Controls on Dust Exposures During Masonry Activities. Master's thesis, University of Washington, Seattle, WA (2000).

17. Nash, N.T.; Williams, D.R.: Occupational Exposure to Crystalline Silica During Tuckpointing and the Use of Engineering Controls. Appl Occup Environ Hyg 15(1):8–10 (2000).
18. Gressel, M.G.; Echt, A.S.; Almaguer, D.; Gunderson, L.: Control Technology and Exposure Assessment for Occupational Exposure to Crystalline Silica: Case 23—Masonry Tuck-Pointing. NIOSH Report No. ECTB 233-123c. NIOSH, Cincinnati, OH (1999).
19. Heitbrink, W.A.; Watkins, D.: In-Depth Study Report: Control Technology for Crystalline Silica Exposures in Construction: The Effect of Exhaust Flow Rate Upon the Respirable Dust Emissions for Tuck Pointing Operations and a Preliminary Evaluation of a Ventilated Tool for Brick Cutting. Report # EPHB NO 247-18. NIOSH, Cincinnati, OH (2001).
20. NIOSH: Environmental Surveillance Report Baker Concrete Construction. NIOSH, Cincinnati, OH (1998).
21. Gressel, M.G.; Echt, A.S.; Almaguer, D.; Gunderson, L.: Control Technology and Exposure Assessment for Occupational Exposure to Crystalline Silica: Case 04—A Concrete Finishing Operation. NIOSH Report No. ECTB 233-104c. NIOSH, Cincinnati, OH (1999).
22. Akbar-Khanzadeh, F.; Brillhart, R.L.: Respirable Crystalline Silica Dust Exposure During Concrete Finishing (Grinding) Using Hand-Held Grinders in the Construction Industry. Ann Occup Hyg 46(3):341–346 (2002).
23. Flanagan, M.E.: Surface Grinding Dust Control Evaluation. Downloaded from website http://depts.washington.edu/cnstsafe/cnst_research.htm on 3/28/01.
24. Thorpe, A.; Ritchie, A.S.; Gibson, M.J.; Brown, R.C.: Measurements of the Effectiveness of Dust Control on Cut-Off Saws Used in the Construction Industry. Ann Occup Hyg 43(7):443–456 (1999).
25. Flanagan, M.E.: Masonry Saw Ventilation Evaluation for Jobsite Concrete Cutting. Downloaded from website http://depts.washington.edu/cnstsafe/cnst_research.htm on 3/28/01.
26. Flanagan, M.E.: Wet Concrete Saw Cutting Inside—How Much Water Is Enough. AIHACE Abstracts New Orleans, June 2001.
27. Gressel, M.G.; Echt, A.S.; Almaguer, D.; Cleary. J.N.; Gunderson, L.: Control Technology and Exposure Assessment for Occupational Exposure to Crystalline Silica: Case 15—Concrete Cutting. NIOSH Report No. ECTB 233-115c. NIOSH, Cincinnati, OH (1999).
28. Gressel, M.G.; Echt, A.S.; Almaguer, D.; Cleary, J.N.; Gunderson, L.: Control Technology and Exposure Assessment for Occupational Exposure to Crystalline Silica: Case 16—Wet Cutting of Concrete Masonry Units. NIOSH Report No. ECTB 233-116c. NIOSH, Cincinnati, OH (1999).
29. Gressel, M.G.; Echt, A.S.; Almaguer, D.; Cleary, J.N.; Gunderson, L.: Control Technology and Exposure Assessment for Occupational Exposure to Crystalline Silica: Case 17—Dry Cutting of Concrete Masonry Units. NIOSH Report No. ECTB 233-117c. NIOSH, Cincinnati, OH (1999).
30. Gressel, M.G.; Echt, A.S.; Almaguer, D.; Cleary, J.N.; Gunderson, L.: Control Technology and Exposure Assessment for Occupational Exposure to Crystalline Silica: Case 18—Cutting Brick and Concrete Masonry Units. NIOSH Report No. ECTB 233-118c. NIOSH, Cincinnati, OH (1999).
31. Gressel, M.G.; Echt, A.S.; Almaguer, D.; Gunderson, L.: Control Technology and Exposure Assessment for Occupational Exposure to Crystalline Silica: Case 22—Rock Drilling. NIOSH Report No. ECTB 233-122c. NIOSH, Cincinnati, OH (1999).
32. Flanagan, M.E.: Green River Bridge Project Silica Exposure Assessment. Downloaded from website http://depts.washington.edu/cnstsafe/cnst_research.htm on 3/28/01.
33. Tsuji, K.; Fukuhara, I.: Protection of Breathing Zone by Uniform Velocity Blowing. I. AIHA J 61:568–574 (2000).
34. Bulte, N.; Woskie, S.; Greenspan, C.: Exposure Characterization for Highway Construction Part I: Cut and Cover Tunnel Finnish Stages. Appl Occup Environ Hyg 14(9):632–641 (1999).
35. Riala, R.: Dust and Quartz Exposure of Finnish Construction Site Cleaners. Ann Occup Hyg 32(2):215–220 (1988).
36. Lehtinen, J.H.; Koski, H.; Enbom, S.: Use of a Central Vacuum System at a Renovation Site Technical Research Center of Finland (VTT). Espoo (1996).