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REPORT

Effect of hollow bit local exhaust ventilation on respirable quartz dust concentrations during concrete drilling

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ABSTRACT
Drilling large holes (e.g., 10–20 mm diameter) into concrete for structural upgrades to buildings, highways, bridges, and airport runways can produce concentrations of respirable silica dust well above the ACGIH® Threshold Limit Value (TLV® = 0.025 mg/m^3). The aim of this study was to evaluate a new method of local exhaust ventilation, hollow bit dust extraction, and compare it to a standard shroud local exhaust ventilation and to no local exhaust ventilation. A test bench system was used to drill 19 mm diameter x 100 mm depth holes every minute for one hour under three test conditions: no local exhaust ventilation, shroud local exhaust ventilation, and hollow bit local exhaust ventilation. There were two trials for each condition. Respirable dust sampling equipment was placed on a "sampling" mannequin fixed behind the drill and analysis followed ISO and NIOSH methods. Without local exhaust ventilation, mean respirable dust concentration was 3.32 (± 0.65) mg/m^3 with a quartz concentration of 16.8% by weight and respirable quartz dust concentration was 0.55 (± 0.05) mg/m^3; 22 times the ACGIH TLV. For both LEV conditions, respirable dust concentrations were below the limits of detection. Applying the 16.8% quartz value, respirable quartz concentrations for both local exhaust ventilation conditions were below 0.007 mg/m^3. There was no difference in respirable quartz dust concentrations between the hollow bit and the shroud local exhaust ventilation systems; both were below the limits of detection and well below the ACGIH TLV. Contractors should consider using either local exhaust ventilation method for controlling respirable silica dust while drilling into concrete.

KEYWORDS
Concrete; exposure control; masonry; silica; tool design

Introduction

Large diameter holes (1–3 cm diameter) are drilled into concrete in commercial construction for structural upgrades (e.g., dowel and rod drilling) and for inserting anchor bolts for hanging pipes, conduit, or equipment. For dowel and rod drilling, a hole is drilled, then thoroughly brush-cleaned before epoxy is injected into the hole and rebar or dowel is inserted. For anchor bolts, the hole is drilled then the anchor bolt is pounded into the hole and tightened so that a wedge expands the insert and secures the bolt in the concrete. Anchor bolts can also be secured with epoxy or they can be screwed into concrete. Industrial construction projects may require thousands of these holes to be drilled, and this work can generate high concentrations of respirable silica dust, concentrations well in excess of the ACGIH Threshold Limit Value (TLV) of 0.025 mg/m^3,[1] depending on the drill used, size of hole drilled, frequency of drilling, and environmental conditions.[2–6] Respirable silica dust can cause silicosis and lung cancer; [7] therefore, US OSHA recently reduced the permissible exposure limit (PEL) to 0.05 mg/m^3.[8]

Local exhaust ventilation (LEV) using a shroud or hood system can be effective in reducing respirable silica dust concentrations during concrete drilling. In a study involving several trials of drilling 7/8" diameter holes every two min for 25 min into concrete with a pneumatic rock drill, the shroud LEV reduced respirable silica dust from 0.68 to 0.04 mg/m^3.[9] In another study at a training center, different shroud systems (e.g., ring hood and bellows hood) were used to repeatedly drill into concrete. The shroud LEV systems reduced respirable silica dust concentrations from 0.308 mg/m^3 to between 0.006 and 0.028 mg/m^3.[10]

Hollow bit LEV systems for dust capture during concrete drilling have recently become commercially

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available for drilling holes for anchors and dowel drilling. Two advantages of this approach are that (1) it may improve dust extraction from the hole and thereby improve epoxy attachment, and (2) it eliminates the time required to brush-clean the holes prior to inserting epoxy. However, the effectiveness of hollow bit systems to reduce respirable silica dust has not been evaluated. The purpose of this study was to use a test bench system to measure respirable quartz dust concentrations under three dust extraction conditions: no LEV, shroud LEV, and hollow bit LEV.

Methods

The study was conducted using a test bench system previously described.[11] A mass and pulley system advanced the drill under constant load (88N force on bit—adjusted for system friction). The test bench system automatically drilled a hole approximately every minute into a concrete block then automatically moved the block to a new location in preparation for the next hole. Non-reinforced concrete blocks (610 mm depth; 305 mm width; 610 mm height) were prepared on site, as previously described, and cured for at least 28 days.

An electric rotary hammer drill (Hilti TE-70 ATC, Hilti Corp., Schaan, Lichtenstein) was fitted with a new 19 mm (3/4") diameter 2-carbide tipped bit for each trial. The drill was held at the handle with a four-fingered rubber lined mechanical gripper and supported at the chuck by a rubber-lined Y fixture.

Three LEV conditions were tested: no LEV, shroud LEV, and hollow bit LEV. The no LEV condition used a conventional bit (Hilti TE-Y ¾" x 21"). The shroud LEV condition (Figure 1) used a conventional bit with a telescoping shroud (Hilti DRS-S) connected to a vacuum (Hilti VC-150, max flow rate 72 L s^{-1}). The hollow bit LEV condition (Figure 2) (Hilti TE-YD ¾" x 24") used the same vacuum. The vacuum was fitted with a new fleece bag (Hilti 2121562) and HEPA filter (Hilti 436058) before each trial.

Two drilling trials were conducted for each LEV condition. For each trial, the test bench drilled 60 holes over approximately 70 min. Each 19 mm diameter hole was drilled to a depth of 100 mm. The vacuum and room were cleaned and wiped down between trials. An air cleaner (Aircube 2000, Dustcontrol Inc, Wilmington, NC) was operated between trials until the respirable dust concentration returned to the levels recorded before the start of the trial. A direct-reading aerosol monitor (DustTrak DRX 8533, TSI Inc., Shoreview, MN) was located in the room to confirm that the dust concentration returned to baseline after cleaning.

Figure 1. Shroud LEV test condition. The cyclone is located on the mannequin for respirable air sampling.

Figure 2. Hollow bit LEV test condition. The drill is advanced automatically, under force control into the concrete block. After a hole is drilled, the block is automatically advanced to position the next hole.

Respirable silica dust sampling followed ISO and NIOSH standards. A "sampling" mannequin was fixed behind the drill in a location similar to where a worker would be. During each trial, a respirable dust sample (4 µm median cut point) was collected within 30 cm of the mannequin's nose or mouth. The sampler was a GK 4.162 cyclone (BGI by Mesa Labs, Inc., Butler, NJ) holding a pre-weighed 47 mm polyvinyl chloride filter. A portable battery-powered pump (model SG10–2; GSA Messgerätebau GmbH, Neuss,

Table 1. Mean (SD) respirable dust and respirable quartz dust concentrations by LEV condition.

	No LEV	Shroud LEV	Hollow Bit LEV
Number of trials	2	2	2
Number of holes per trial	60	60	60
Respirable dust (mg/m^3)	3.32 (0.65)	<0.124	<0.143
Respirable quartz by weight (%)	16.8 (1.9)	16.8*	16.8*
Respirable quartz dust (mg/m^3)	0.55 (0.05)	<0.007	<0.007

*Used values from the "No LEV" samples, as concentrations were below LOD in all samples using LEV.

Germany) was used to draw air through the sampler and was calibrated to provide a flow rate of 9 L min^{-1}. The pump was calibrated before each session and verified after each sampling session with a digital volumetric flow meter (model 4146 primary calibrator; TSI Inc., Shoreview, MN).

The filter-based samples collected with the BGI cyclone were analyzed by an accredited analytical laboratory (R.J. Lee Group, Inc., Monroeville, PA) using NIOSH method 0600 to determine the respirable mass and NIOSH method 7500 to determine percent crystalline silica (quartz, cristobalite, and tridymite by X-ray diffraction) in the respirable mass. T-test statistics were used to compare the mean respirable dust and mean respirable quartz dust concentrations between LEV conditions. Sample values below the limit of detection (LOD) were analyzed in statistical comparisons by using $LOD/\sqrt{2}$.[12]

Results

Without LEV, the mean respirable dust concentration was 3.32 mg/m^3, the mean quartz concentration was 16.8% by weight, and the mean respirable quartz dust concentration was 0.55 mg/m^3 (Table 1). For both LEV conditions the respirable dust concentrations were below the limits of detection (<0.14 mg/m^3) and were significantly less than without LEV ($p = 0.02$). The limits of detection for each trial differed due to small differences in sampling duration. Concentrations from samples collected using LEV were too small to evaluate quartz concentrations; therefore, the mean 16.8% value from the no LEV condition was used to calculate respirable quartz concentrations for the LEV conditions. Respirable quartz dust concentrations with LEV were significantly less than without LEV ($p = 0.004$).

Discussion

Both LEV systems reduced respirable quartz dust concentrations by more than 98% to levels that were approximately 25% below the ACGIH TLV (0.025 mg/m^3). When no LEV was used, the respirable quartz concentration was 22 times the ACGIH TLV; therefore, respiratory protection would be required. While there was no difference in respirable quartz concentrations between the two LEV systems, the effectiveness of the shroud system will be reduced if the shroud is not well sealed against the concrete surface. This can occur if the drilling is not perpendicular to the surface, the concrete surface is uneven, or the shroud is pulled back by the construction worker. The shroud might be pulled back in order for the worker to confirm that the bit is penetrating the concrete at the proper location. The effectiveness of the hollow bit LEV system is not anticipated to be influenced by concrete surface conditions or drilling angle.

There are no prior studies evaluating the effectiveness of hollow bit LEV for concrete drilling; however, there are studies demonstrating effectiveness for hollow bit LEV for rock drilling.[13] The few prior studies of shroud LEV systems for concrete drilling reported large reductions in respirable silica. A study at a training center involving workers drilling without and with different shroud and vacuum systems found that respirable quartz concentrations were reduced from 0.308 mg/m^3 without LEV to a range of 0.006–0.028 mg/m^3 with LEV;[10] the average reduction in respirable quartz was 94%. The drilling was done repeatedly for 1 hr for each LEV condition and for 15 min for the no LEV condition. The bit diameter was 9 mm (3/8 in.) and the drilling depth 7.6 cm; however, the frequency of holes drilled was not reported. For the no LEV condition, the respirable quartz concentration was lower than our study measured. The difference may be due to the duration of drilling (15 vs. 60 min), bit diameters, and the volume of concrete removed. Another laboratory study evaluated many different drills, LEV systems, and concrete drilling tasks.[14] However, only two of the tests with and without LEV were performed under identical conditions (Kango 637 and 950). These demonstrated a 97% reduction in respirable quartz concentrations due to a shroud LEV system. When using large pneumatic drills for dowel drilling, shroud LEV systems can reduce dust emissions by 87–93%.[9,15]

The methods of the automated test bench system used in this study deviate somewhat from the recommendations of the European Standard for measuring dust during concrete drilling in a laboratory.[16] The European Standard calls for having skilled operators do the drilling. This will, to some extent, mimic differences in methods used by workers in the field. However, the operator will also introduce variance due to differences in drilling technique. The test bench system reduces this variance: it produces reliable perpendicular drilling every time. The other methods of the test bench system generally followed the recommendations of the European Standard.

Generalizing the findings to construction sites should be done with caution. The high repetition rate for hole drilling and the small volume of the test bench room with no air exchange creates a worst-case condition. Drilling in an enclosed space will likely lead to higher cumulative dust concentrations than drilling in large or open spaces where there is good air exchange. Most drilling at construction sites is conducted in large open spaces with air movement.

Conclusions and recommendations

The hollow bit LEV was as effective as the shroud LEV in reducing respirable quartz dust concentrations, with both methods resulting in concentrations well below the 0.025 mg/m^3 ACGIH TLV. In this test bench laboratory study, the exposures generated without using the LEV would require the driller to wear respiratory protection, while with either LEV option the concentrations were sufficiently reduced. The test bench study produced high concentrations of dust due to the high drilling frequency, large volume of concrete removed, no air exchange, and the small volume of the room. This produced higher concentrations than would be expected to be found in the field. On the other hand, the dust capture was optimized for both LEV methods with the use of a new HEPA filter vacuum, sealed hoses, and a new dust capture bag for each trial, which may represent a best-case scenario for dust collection compared to field use. The shroud LEV functions optimally when the bit and shroud are perpendicular to the concrete surface and the concrete surface is smooth; both conditions were guaranteed by the bench system, but these conditions are not likely to represent conditions in the field. However, the hollow bit LEV is likely to function well even if the bit is not perpendicular to the concrete surface or the concrete surface is uneven. This study indicates that respirable silica exposures in the field may be substantially reduced when using either of these LEV devices; field assessments should be conducted to confirm that they control exposures to concentrations below levels requiring respiratory protection.

Disclaimer

The findings and conclusions in this report are solely those of the authors and do not necessarily represent the official views of CPWR or NIOSH. Mention of product names does not imply endorsement. The authors identify no conflicts of interest in the conduct of this study.

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