Comprehensive Report

Laboratory evaluation of power shears for cutting fiber-cement siding

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Abstract

Workplace exposure to respirable crystalline silica can cause silicosis, a progressive lung disease marked by scarring and thickening of the lung tissue. Quartz is the most common form of crystalline silica. Crystalline silica is found in several construction materials, such as brick, block, mortar, and concrete. Construction tasks that cut, break, grind, abrade, or drill those materials have been associated with overexposure to dust containing respirable crystalline silica. Fiber-cement products can contain as much as 50% crystalline silica and cutting this material with power saws has been shown to cause excessive exposures to respirable crystalline silica. NIOSH scientists conducted this study to evaluate power shears for cutting fiber-cement siding.

Detailed characterizations of the dust generated from cutting fiber-cement siding using either power shears or a dust-collecting circular saw (C-M saw) were conducted in a laboratory setting. The C-M saw was tested with and without local exhaust ventilation (LEV), and the results of those tests were compared. For all the test conditions (the power shears and the C-M saw with and without LEV), particle size data obtained with the Aerodynamic Particle Spectrometer (APS), a real-time direct-reading instrument, showed a lognormal number-based size distribution with geometric mean diameters ranging from 0.9-1.1 µm and geometric standard deviations ranging from 1.5-1.8. The C-M saw without LEV generated the largest amount of dust with an average total number concentration of 5,695 particles/cm^3, estimated from fitting the data to a lognormal distribution. The test of the C-M saw with LEV (with an exhaust air flow rate of 2.54 m^3/min or ~90 CFM) resulted in an estimated total number concentration of 564 particles/cm^3, which corresponds to a ~90% reduction compared to using the saw without LEV. The power shears generated the least amount of dust, with an estimated total number concentration of only 34 particles/cm^3, which is 94% lower than the C-M saw with LEV and 99.4% lower than the C-M saw without LEV. The mass-based size distributions showed a similar trend overall, with the power shears generating considerably less dust, even when the results were compared to the C-M saw with LEV.

The laboratory testing system provides reliable characterization of the respirable dust generation rate, G_{APS} (expressed as grams of dust per meter of board cut, g/m), from cutting fiber-cement siding with different tools. The G_{APS} derived from the APS data for the power shears was significantly lower than that for the C-M saw with LEV (a mean of 0.0059 g/m versus 0.0289 g/m, $P<0.001$), which in turn, was significantly lower than that for the C-M saw without LEV (a mean of 0.0289 g/m versus 0.4003 g/m, $P<0.001$). The results from the laboratory tests suggest that the reduction of G_{APS} from using LEV with dust-collecting circular saws is largely in agreement with the previously reported exposure reductions obtained from field surveys of construction sites where this control measure was used. The significantly lower G_{APS} for the power shears compared to that of the C-M saw with or without LEV indicates that cutting fiber-cement siding using similar power shears could be expected to result in an 8-hr TWA exposure to respirable crystalline silica lower

than those observed in the field surveys using dust collection circular saws with LEV (0.013±0.009 mg/m^3) and without LEV (0.084±0.055 mg/m^3). From the perspective of exposure control, the use of power shears whenever practical is a preferred method for cutting fiber-cement siding, and its use adheres to the hierarchy of controls.

Introduction

Background for Control Technology Studies

The National Institute for Occupational Safety and Health (NIOSH) is the primary Federal agency engaged in occupational safety and health research. Located in the Department of Health and Human Services, it was established by the Occupational Safety and Health Act of 1970. This legislation mandated NIOSH to conduct a number of research and education programs separate from the standard setting and enforcement functions carried out by the Occupational Safety and Health Administration (OSHA) in the Department of Labor. An important area of NIOSH research deals with methods for the identification, characterization and control of occupational exposures to potential chemical and physical hazards. The Engineering and Physical Hazards Branch (EPHB) of the Division of Applied Research and Technology has been given the lead within NIOSH to study the engineering aspects of health hazard prevention and control.

Background for this Study

Crystalline silica refers to a group of minerals composed of silicon and oxygen; a crystalline structure is one in which the atoms are arranged in a repeating three-dimensional pattern [Bureau of Mines 1992]. The three major forms of crystalline silica are quartz, cristobalite, and tridymite; quartz is the most common form [Bureau of Mines 1992]. Respirable crystalline silica refers to that portion of airborne crystalline silica dust that is capable of entering the gas-exchange regions of the lungs if inhaled; this includes particles with aerodynamic diameters less than approximately 10 micrometers (μm) [NIOSH 2002]. Silicosis, a fibrotic disease of the lungs, is an occupational respiratory disease caused by the inhalation and deposition of respirable crystalline silica dust [NIOSH 1986]. Silicosis is irreversible, often progressive (even after exposure has ceased), and potentially fatal. Because no effective treatment exists for silicosis, prevention through exposure control is essential.

NIOSH Recommended Exposure Limit (REL) sets an exposure limit for respirable crystalline silica of 0.05 milligrams per cubic meter (mg/m^3) as a time weighted average (TWA) determined during a full-shift sample for up to a 10-hour (hr) workday during a 40-hr workweek to reduce the risk of developing silicosis, lung cancer, and other adverse health effects [NIOSH 2002]. When source controls cannot keep exposures below the NIOSH REL, NIOSH also recommends minimizing the risk of illness that remains for workers exposed at the REL by substituting less hazardous materials for crystalline silica when feasible, by using appropriate respiratory protection, and by making medical examinations available to exposed workers [NIOSH 2002]. In March 2016, OSHA issued a new Permissible exposure limit (PEL) of 0.05 mg/m^3 for 8-hr TWA exposures [81 Fed. Reg.[1] 16285 (2016)]. The Threshold Limit Values® (TLVs®) recommended by the American Conference of

[1] *Federal Register.* See Fed. Reg. in references.

Governmental Industrial Hygienists (ACGIH®) for α-quartz and cristobalite (respirable fraction) is 0.025 mg/m^3 [ACGIH 2016]. The TLV is intended to mitigate the risk of pulmonary fibrosis and lung cancer. When dust controls are not used or maintained or proper practices are not followed, respirable crystalline silica exposures can exceed the NIOSH REL, the OSHA PEL, or the ACGIH TLV.

Crystalline silica is a constituent of several materials commonly used in construction, including brick, block, and concrete. Many construction tasks have been associated with overexposure to dust containing crystalline silica [Chisholm 1999; Flanagan et al. 2003; Rappaport et al. 2003; Woskie et al. 2002]. Among these tasks are tuckpointing, concrete cutting, concrete grinding, abrasive blasting, and road milling [Nash and Williams 2000; Thorpe et al. 1999; Akbar-Khanzadeh and Brillhart 2002; Glindmeyer and Hammad 1988; Linch 2002; Rappaport et al. 2003]. Fiber-cement products can contain as much as 50% crystalline silica. Cutting this material with power saws has been shown to cause excessive exposures to respirable crystalline silica [Lofgren et al. 2004; Qi et al. 2013].

The use of fiber-cement siding in construction and renovation is undergoing rapid growth. From 1991 to 2010, the market share of fiber-cement siding has climbed from 1% to 13% [US Census Bureau 2013]. In contrast, the market share of wood siding in residential construction has decreased from 38% to 8% [US Census Bureau 2013]. The durability and appearance of fiber-cement siding, which simulates wood without the maintenance issues associated with wood siding, is appealing and reportedly provides a competitive advantage over other building materials [Bousquin 2009]. The use of fiber-cement siding is expected to continue to increase. The number of workers exposed to dust containing crystalline silica as a result can also be expected to increase as the use of fiber-cement siding displaces other siding products. Cellulose fiber, sand or fly ash, cement, and water are the principal ingredients used in the manufacture of fiber-cement products. James Hardie (Mission Viejo, California), CertainTeed (Valley Forge, PA), Maxitile (Houston, TX), GAF (Wayne, NJ), and Nichiha (Norcross, GA) are the major manufacturers of fiber-cement products.

Fiber-cement board is cut using three methods: scoring and snapping the board, cutting the board using shears, and cutting the board using power saws. When scoring and snapping the board, a knife is used to score the board by scribing a deep line into the board. The board is bent, and it breaks along the scored line. This method should be relatively dust-free. The score and snap method can be used when installing fiber-cement board used for tile underlayment, but is not applicable to siding. Commercially available tools used to shear fiber-cement siding include foot-powered shears and hand-held shears that may be manual or use a power source. Power saws, such as circular saws and compound miter saws, are used to cut fiber-cement siding. These saws are normally used with 4-8 tooth polycrystalline diamond-tipped (PCD) blades specifically designed to cut fiber-cement siding and minimize dust generation. Several commercially available saws are manufactured with hoods and exhaust take-offs that can be connected to vacuum cleaners or to dust-collection bags. These hoods partially enclose the saw blade. Available blade diameters are 5, 7.25, 10, and 12 inches (12.7, 18.4, 25.4, and 30.5 cm, respectively).

For workers using power saws, the study by Lofgren et al. [2004] reported that their uncontrolled exposures to respirable crystalline silica ranged from 0.02 to 0.27 mg/m^3 during sampling, and their 8-hr TWA exposure ranged from 0.01 to 0.17 mg/m^3 depending on the length of exposure on the day sampled. The highest result was 3.4 times the NIOSH REL for respirable crystalline silica of 0.05 mg/m^3. In an in-depth field survey, Qi et al. [2013] reported that a cutter's uncontrolled exposures to respirable crystalline silica ranged from 0.06 to 0.13 mg/m^3 when using power saws during sampling, and their 8-hr TWA exposure ranged from 0.02 mg/m^3 to 0.13 mg/m^3 depending on the length of exposure on the day sampled. The highest result was 2.6 times the NIOSH REL for respirable crystalline silica of 0.05 mg/m^3.

The data from both field surveys suggested excessive exposures to respirable crystalline silica occurred when an engineering control was not used for cutting fiber-cement siding with power saws. Qi et al. [2014] reported a simple and low cost engineering control measure by attaching a regular shop vacuum to a dust-collecting circular saw for cutting fiber-cement siding. Three circular saws were evaluated in a laboratory study. All of them featured a built-in dust collection container or shroud, which served as a hood and partially enclosed the saw blade for collecting dust while cutting. The dust removal efficiency for the circular saws was greater than 78% even at a low flow rate of 0.83 m^3/min [29 cubic feet per minute (CFM)] for the LEV system used. The results from the laboratory evaluation suggested that connecting a dust-collecting circular saw to a basic shop vacuum with built-in air filters had the potential to provide a simple and low-cost engineering control measure for the dust generated from cutting fiber-cement siding. Four field surveys were conducted to validate the effectiveness of the engineering control measure suggested from the laboratory evaluation. The survey results showed that the 10-hour TWA exposure to respirable crystalline silica for the workers who mainly cut fiber-cement siding on the job sites was well under control, with the 95% upper confidence limit being only 24% of the NIOSH REL. This engineering control measure effectively reduced occupational silica exposures and provided an effective, simple and low cost solution for workers cutting fiber-cement siding.

In this study, the dust generated from cutting fiber-cement siding using power shears was characterized in a laboratory setting and compared to that generated from one of the three previously tested dust-collecting circular saws with and without the use of LEV. The results can be used to estimate the exposure levels for workers cutting fiber-cement siding using similar power shears.

Materials and Methods in the Laboratory Evaluation

Laboratory Testing System

A worker's exposure to respirable crystalline silica during construction work can vary due to weather conditions, construction materials involved, work location, type of work performed, task duration and frequency, work practices, personal protective equipment (PPE), and whether or not dust control measures were used. Laboratory evaluation of dust generation and dust controls is an approach to control testing that permits those sources of variation to be controlled. Figure 1 illustrates a diagram of the laboratory testing system used in this study. The overall dimension and components of the system were similar to those used by Beamer et al. [2005], Heitbrink and Bennett [2006], and Carlo et al. [2010], and they were consistent with European Standard EN 1093-3 [CEN 2006]. A dust collection air handling unit (PSKB-1440, ProVent LLC, Harbor Springs, MI) was used as an air mover for the system. The air handling unit was connected to an automatic tool testing chamber through a 0.3 meter (m) diameter duct about 6.4 m long. A funnel section connected the duct to the automatic tool testing chamber, which had a square cross section of 1.2 m wide and 1.2 m high. A blast gate upstream of the air handling unit was used to adjust the air flow rate passing through the testing system by allowing the excessive air to enter the air handling unit through the gate. Once turned on, the air handling unit was set to draw room air into the testing system at a flow rate of 0.64 m^3/second (m^3/sec, equivalent to 1350 cubic feet per minute, CFM). This flow rate was set by manually adjusting the blast gate valve and was monitored by a micromanometer (PVM100 Airflow Developments Ltd., UK) connected to a delta tube (306AM-11-AO, Midwest Instrument, Sterling, MI). Delta tube functioned as an averaging pitot tube and has four pressure-averaging ports on the front and backside of a tear-shaped or circular cylinder [Miller 1989]. The Delta tube used in this study has a tear-shaped cylinder and it was mounted on the duct about 2.4 m downstream (8 times of the duct diameter) of the funnel section. The accuracy of the flow rate measured by the Delta tube was verified by comparing the flow rate obtained from its manufacturer's calibration equation [Mid-West Instrument, 2004] and that measured by Heitbrink and Bennett [2006] using a 10-point pitot tube traverse of the duct performed in the horizontal and vertical planes (about 0.8% difference). An aerosol sampling port was open on the duct for mounting a sampling probe of the sampling instrument used in this study. The locations of the Delta tube and sampling port on the duct were chosen to meet the requirements of European Standard EN 1093-3 [CEN 2006] for taking representative samples.

The air flow that entered the system first passed through a filter panel, which had the same cross section as the automatic tool testing chamber and was 0.7 m long. The filter panel included one bank of four pre-filters and another bank of four HEPA filters that removed all the particles in the room air so that they did not interfere with the analysis of the dust generated inside the testing system. The filters also helped ensure that the air that entered the system had a uniform velocity profile across the panel's cross section. After the filtration section was the automatic tool testing chamber, which was 4.9 m long and was specifically designed and constructed for this study. Under the operating air flow rate, the flow velocity in the chamber was 0.44 m/sec, which is sufficient to transport respirable dust to the sampling section of the system, according to European Standard EN 1093-3 [CEN 2006]. The Reynolds numbers for the chamber and duct are 34,000 and 170,000, respectively, indicating turbulent flow, which helped maximize mixing to obtain an appropriately representative sample at the sampling section. The air handling unit collected all the dust generated in the testing system with two filter cartridges (P25.20, ProVent LLC, Harbor Springs, MI) before the cleaned air was discharged back into the room.

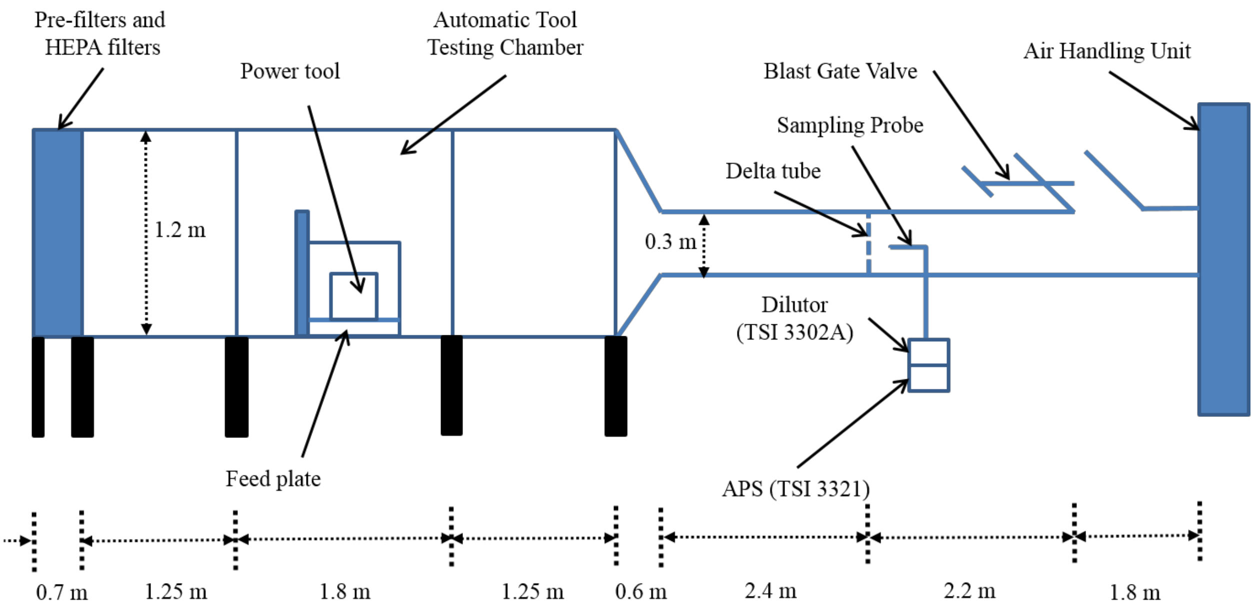


Figure 1. Diagram of the Laboratory Testing System.

The walls of the automatic tool testing chamber were transparent so the operation inside could be observed. The chamber featured automatic control using a Programmable Logic Controller (PLC) and a Human Machine Interface (HMI). Power shears (Model 404, PacTool International, Kingston, WA) and a circular saw (Model 5057KB, referred to as C-M saw, Makita U.S.A., Inc., St. La Mirada, CA) were mounted in the chamber using a variety of fixtures for evaluation. The operations of these power tools were controlled using a two-dimensional actuator through the PLC. A fiber-cement siding board manufactured by CertainTeed (manufacturing date of 05/27/2012, Valley Forge, PA) was mounted on a chain-driven feed plate, and the feed rate was automatically controlled through the PLC. The fiber-cement siding board had a width (W) of 21.0 centimeter (cm), a thickness of 0.76 cm, and a measured density of 1.31±0.03 gram/cm^3 (g/cm^3). Board feed rate and power tool operation were programmed through the HMI so that automatic and repeatable cuts were achieved.

The C-M saw has a specified no-load rotating speed of 5,800 revolutions per minute (RPM). A Pocket Tachometer (Model TAC2K, Dwyer Instruments Inc., Michigan City, IN) provided an actual no-load rotating speed reading of 5,500 RPM for the C-M saw. A 4-tooth Polycrystalline Diamond (PCD) blade (blade diameter of 18.4 cm or 7.25 inch, Model 18008, Hitachi Power Tools, Valencia, CA) was used with the C-M saw in this study. Qi et al. [2016] reported that this blade generated the least amount of respirable dust among the three tested blades of the same diameter.

Local Exhaust Ventilation (LEV)

An exhaust port on the bottom of the automatic tool testing chamber allowed connection of the exhaust port on the C-M saw to an external vacuum cleaner (Model 3700, Dustcontrol, Sweden) through flexible hoses. The external vacuum cleaner provided LEV of up to 5.0 m^3/min (175 CFM) to the power saws. In the Dustcontrol 3700 vacuum cleaner, larger dust particles collect in an attached dust bag after running through an internal cyclone collector, and the escaped smaller dust collects in a HEPA filter cartridge downstream of the cyclone collector. Figure 2 shows how the LEV system was regulated and monitored. A T-shape PVC pipe was connected to the vacuum cleaner, and a gate valve was installed on the two branches. By adjusting the two gate valves, a ventilation flow rate in the full range of the vacuum cleaner's suction capacity was obtained for the test. The flow rate was monitored by a micromanometer (PVM100 Airflow Developments Ltd., UK) connected to a delta tube (307BZ-11-AO, Midwest Instrument, Sterling, MI).

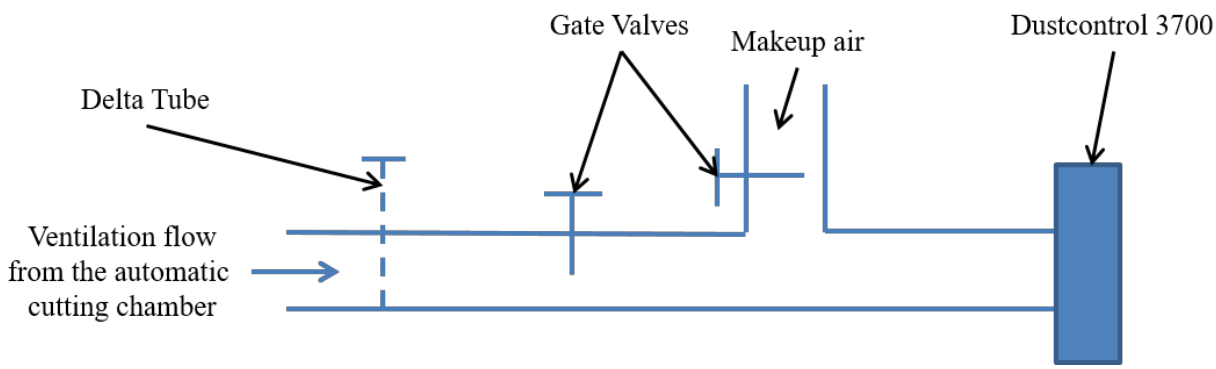


Figure 2. Diagram of the Local Exhaust Ventilation (LEV) system used in this study.

Sampling Methods

In this study, the automatic tool testing chamber was set to make a fixed number of repeat cuts of the fiber-cement siding board for each test condition. An Aerodynamic Particle Spectrometer (APS, model 3321, TSI Inc, Shoreview, MN) provided real-time direct reading measurement of the size distribution of the dust generated with a 1-second time resolution. The APS continuously collected an aerosol stream from one of two available duct sampling ports at a 5 Liter per minute (L/min) flow rate. The APS used a time-of-flight technique to measure the aerodynamic diameter of the individually counted particles in the range from 0.5 to 20 micrometers (µm). The APS output connected to a computer and the Aerosol

Instrument Manager® Software (AIM V8.1, TSI Inc., Shoreview, MN) collected and analyzed the APS data. In this study, an isokinetic sampling probe was designed for the APS with a matching flow velocity for the inlet of the sampling probe and the duct. The sampling probe bent 90 degrees and vertically connected to an aerosol dilutor (model 3302A; TSI Inc, Shoreview, MN), which sat on top of the APS. The dilutor was configured to provide a 100 to 1 dilution so that measurement uncertainty caused by high concentration aerosols was minimized. The dust size distribution directly measured by the APS is based on number concentration, and it can be used to derive the mass concentration of respirable dust by the following equation:

$$C_m = \sum_{i=1}^{52} \frac{\rho_P f_i \pi d_{e,i}^3 N_i}{6 \eta_{dil,i} \eta_{sp,i}} \qquad (1)$$

where,

C_m is the mass concentration of respirable dust

$d_{e,i}$ is the equivalent volume diameter of channel i in the APS and can be calculated by

$$d_{e,i} = d_{a,i}\sqrt{\rho_0 \chi / \rho_P}$$

$d_{a,i}$ is the aerodynamic diameter of channel i in the APS

ρ_0 is the unit density

ρ_p is the density of the dust

χ is the dynamic shape factor of the dust

f_i is the respirable fraction of the dust with $d_{a,i}$

N_i is the number concentration of the dust with $d_{a,i}$

$\eta_{dil,i}$ is the transportation efficiency of the dust with $d_{a,i}$ through the diluter

$\eta_{sp,i}$ is the transportation efficiency of the dust with $d_{a,i}$ through the sampling probe

The APS directly measures the aerodynamic diameter of the sampled dust, and it classifies the entire size range into 52 channels with $d_{a,i}$ representing the aerodynamic diameter for each specific channel i (i = 1-52). In order to obtain the mass of dust in each channel, its density (ρ_p) is needed, and its equivalent volume diameter needs to be calculated with the knowledge of its density (ρ_p) and dynamic shape factor (χ). In this study, all the dusts generated from cutting fiber-cement siding were assumed to be spherical so their dynamic shape factor was 1. The dust density was also needed for the Stokes correction of the APS data because the APS was calibrated in factory using Polystyrene Latex (PSL) spheres with a density close to 1.05 g/cm^3. Since the APS measures the aerodynamic diameter in a flow velocity of approximately 150 m/sec instead of still air, the Reynolds numbers of the sampled dusts are outside the Stokes regime; a sizing inaccuracy is caused when the dust density is different from 1.05 g/cm^3. The Stokes correction for the APS data can be done by the AIM software with an input of the dust density. However, it is not straightforward to obtain the actual dust density in this study as the bulk material in fiber-cement siding is a mixture of a few different ingredients, and the density might vary depending on the size of the dust. Thus, the measured board density listed in Table 1 was used as the dust density. With the assumed dynamic shape factor and density for the sampled dust, the mass concentration of respirable dusts derived from the APS data and Equation (1) could be different from the actual value. However, this difference should be consistent among all the APS data and should not affect the comparison of the generation rate of respirable dust derived from the APS data under different testing conditions.

In this study, the generation rate of respirable dust (G_{APS}) is defined by the following equation:

$$G_{APS} = \frac{\sum_{t=1}^{T_s} (C_{m,t} Q)}{n_b W} \qquad (2)$$

where,

$C_{m,t}$ is the mass concentration of respirable dusts at time t

Q is the volume flow rate in the testing system, 0.64 m^3/sec

T_s is the total sampling time of the APS for one cut

n_b is the number of boards in the stack, 1 in this report

W is the board width

Since fiber-cement siding in this study was cut by making cross cuts across the board width, the product of n_b and W represents the total linear length for one cut. The total linear length cut is commonly used in practice to account for cutting productivity. The APS data contains one set of dust size distribution for every second during the test, which leads to a $C_{m,t}$ data point for each second using Equation (1). Thus, the summation of $C_{m,t}Q$ during the sampling time T_s results in the total mass of respirable dust generated for one cut. The generation rate of respirable dust defined in Equation (2) represents the mass of respirable dust generated per unit linear length cut.

In this study, the transportation efficiency of dust with $d_{a,i}$ through the diluter ($\eta_{dil,i}$) was provided by the diluter manufacturer and incorporated within the AIM software. The transportation efficiency through the sampling probe ($\eta_{sp,i}$), however, must be analyzed separately. The loss of dust inside the sampling probe can be attributed to the settling loss in the horizontal part of the probe, the inertial loss at the 90 degree bend, and the diffusion loss throughout the probe. These losses are size dependent so the overall loss of respirable dust depends on the size distribution of the dust generated during cutting fiber-cement siding. The overall loss of respirable dust was calculated using the equations summarized by Brockman [2011] and the size distribution data from the APS, and it was found to be less than 1% combining all three aforementioned losses. Thus, $\eta_{sp,i}$ was assumed to be 1 in this study for simplicity.

Operating procedure for a cutting test

Before conducting a cutting test, the automatic tool testing chamber was programmed to perform a pre-determined number of cuts. Each cut included the following steps: 1) the feed plate fed the board; 2) power was supplied to the tool; 3) the 2D actuator moved the tool and made a cut; 4) the tool was turned off; and 5) the 2D actuator moved the tool back to its original position. A waiting time about 5 seconds was programmed between steps 2) and 3) to ensure the blades of the power saws reached their designed rotating speed before making a cut. For both the power shears and C-M saw, the cut was made by sliding the tool through the board. The sliding speed for the tools, referred to as the cutting feed rate in this report, was set to be 2.54 cm/sec by the PLC.

For each cutting test, the air handling unit was turned on and the flow rate set to 0.64 m^3/sec by adjusting the blast gate valve. For a test involving the LEV system, the Dustcontrol 3700 vacuum cleaner was turned on and the flow rate of the LEV system set to a desired point by adjusting the two gate valves. The flow rates of both the testing system and the LEV were stable throughout each individual test of this study. Once the flow rates in the testing chamber and the LEV system reached the desired values, the APS began sampling and the automatic tool testing chamber was started. Upon finishing a test, the air handling unit and the vacuum cleaner were turned off and the APS was turned off.

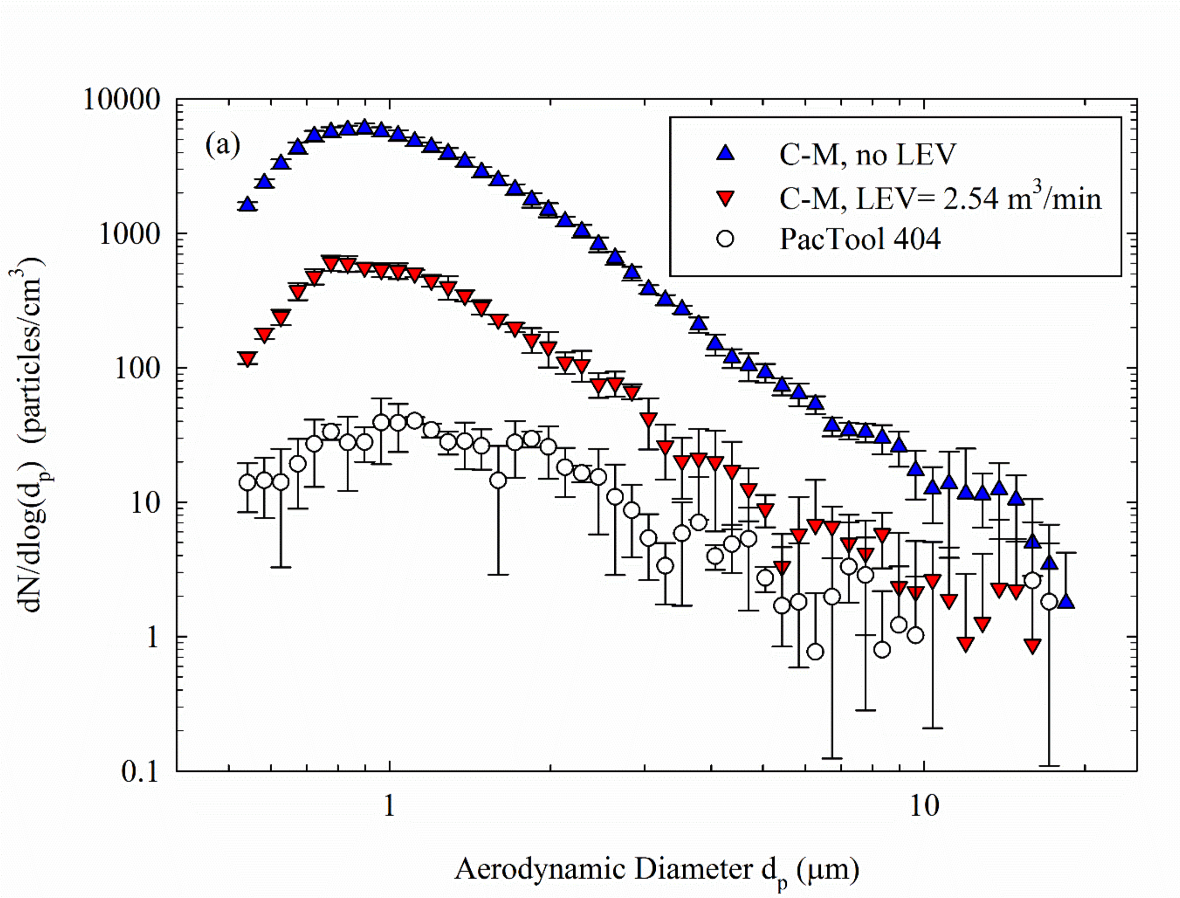
During each cut, a dust cloud was generated, and it was carried downstream by the air flow through the tool testing chamber and measured by the instruments through their respective sampling probes on the duct of the testing system. The APS collected size distribution measurements at 1-second intervals and its data indicated that no dust was detected when no cutting was conducted. The flow rate in the testing chamber (0.64 m^3/sec) was optimal so that the APS data with 1-second time resolution captured the entire profile of the dust cloud from each individual cut without overlapping the dust clouds between any two adjacent cuts for all the testing conditions in this study. This ensured the calculation of the respirable dust generation rate (G_{APS}) using Equation (1) for each individual cut.

Analysis of the APS data from a trial test with at least 15 cuts with the C-M saw under the same testing condition revealed that the relative standard deviation (RSD, the ratio of the standard deviation to the mean) for G_{APS} was about only

3.1%, demonstrating excellent repeatability of the test. With the high repeatability, 3 or more repeated cuts under the same testing condition were considered sufficient to provide statistically reliable results. Thus, 3 cuts were conducted for the PacTool 404 power shears and 5 cuts were conducted for the C-M saw with and without LEV.

Results and Data Analysis for the Laboratory Evaluation

Figure 3 shows the size distributions of the dust generated from cutting fiber-cement siding using the PacTool 404 power shears and the C-M saw. Cutting tests were conducted using the C-M saw with and without LEV. The LEV provided a flow rate of 2.54 m^3/min (~90 CFM) during this test. The size distributions represent the dust concentration (number or mass) per unit width of the instrument's size channel at different aerodynamic diameters. Each data point shown in Figure 3 is the averaged result of 3 or 5 replicates, and the error bars represent the standard deviations of the corresponding data points. The small error bars associated with most data points verify the high repeatability of these tests. The relatively larger error bars for the data points with dN/dlog (d_p) below about 40 particles/cm^3 are due to the higher Poisson uncertainty associated with lower number counts. Thus, the appearance of these larger error bars does not affect the conclusion of the high repeatability of these tests.


10000
1000
100
10
1
0.1
(a)
C-M, no LEV
C-M, LEV= 2.54 m3/min
PacTool 404
1
10
dN/dlog(dp) (particles/cm3)
Aerodynamic Diameter dp (µm)

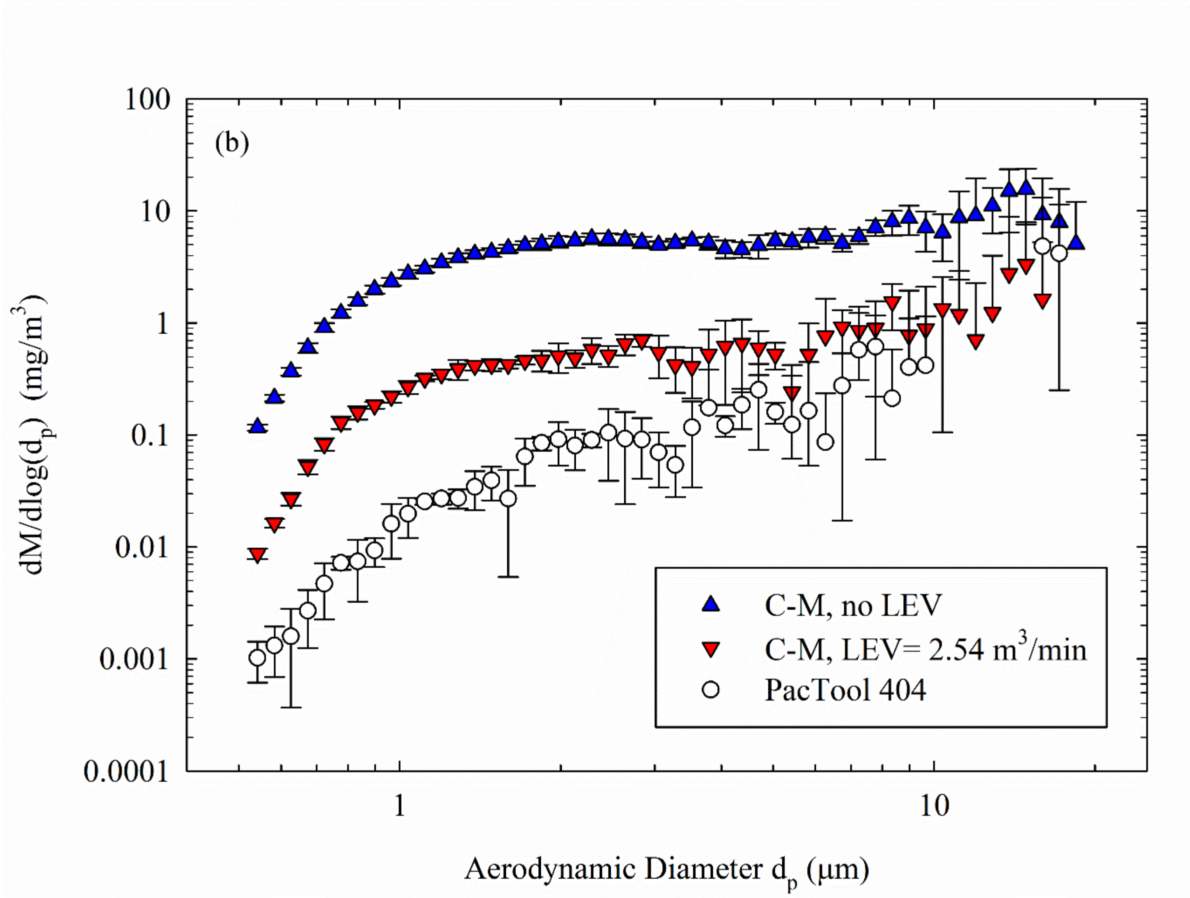


Figure 3. Size distributions of the dust from cutting fiber-cement siding obtained from the APS (a) number-based; (b) mass-based. Cutting feed rate: 2.54 cm/sec.

The number-based size distributions showed a lognormal distribution with a geometric mean diameter ranging from 0.9-1.1 µm and a geometric standard deviation ranging from 1.5-1.8. However, the total number concentration varied considerably among the three tests. The C-M saw without LEV generated the largest amount of dust with an average total number concentration of 5,695 particles/cm^3 as estimated from fitting the data to a lognormal distribution. The test of the C-M saw with LEV (with an exhaust air flow rate of 2.54 m^3/min or ~90 CFM) resulted in an estimated total number concentration of 564 particles/cm^3, which corresponds to a ~90% reduction from the test without LEV. The power shears generated the least amount of dust with an estimated total number concentration of only 34 particles/cm^3, which is 94% lower than the C-M saw with LEV and 99.4% lower than the C-M saw without LEV.

The mass-based size distributions showed a similar trend overall, with the power shears generating considerably less dust even when compared to the C-M saw with LEV. Note that the concentration levels shown in Figure 3 are those monitored in the laboratory setting, which can be very different from those experienced in actual work practice, although the shape of the size distribution is expected to be similar.

A respirable dust generation rate, i.e., G_{APS}, was computed for each cut based on Equation (2), and these are listed in Table 1 for the three test cases. The G_{APS} for the PacTool 404 power shears was significantly lower than that for the C-M saw with LEV (a mean of 0.0059 vs 0.0289 g/m, $P<0.001$), which was in turn significantly lower than that for the C-M saw without LEV (a mean of 0.0289 vs 0.4003 g/m, $P<0.001$).

Table 1. Respirable dust generation rate (G_{APS}, g/m) from the cutting test

Tools	C-M, no LEV	C-M, LEV=2.54 m^3/min (~90 CFM)	PacTool 404
Cut 1	0.4157	0.0267	0.0067
Cut 2	0.4156	0.0289	0.0061
Cut 3	0.3747	0.0287	0.0051
Cut 4	0.4072	0.0334	-
Cut 5	0.3881	0.0269	-
Mean	0.4003	0.0289	0.0059
Standard Deviation	0.0182	0.0027	0.0008

Discussion of the Laboratory Evaluation

As shown in Table 1, the use of LEV operating at 2.54 m^3/min (~90 CFM) provided a 92.8% reduction in the G_{APS} for the C-M saw compared to the use of the C-M saw without LEV. Qi et al. [2014] reported 21 8-hr TWA results from four field surveys for workers cutting fiber-cement siding using the same LEV control for the C-M saw and another dust-collecting circular saw. The actual LEV flow rate monitored during those field surveys was in the range of 1.95-2.96 m^3/min (69-105.8 CFM). The 8-hr TWA exposures to respirable crystalline silica measured in those field surveys ranged from 0.002 mg/m^3 to 0.041 mg/m^3, with a mean of 0.013 mg/m^3 and a standard deviation of 0.009 mg/m^3. This was an 84.1% reduction compared to the 11 8-hr TWA exposures reported for cutting fiber-cement siding using circular saws without LEV (those results ranged from 0.01 mg/m^3 to 0.17 mg/m^3, with a mean of 0.084 mg/m^3 and a standard deviation of 0.055 mg/m^3) [Lofgren et al. 2004; Qi et al. 2013]. The exposure reduction of 84.1% that resulted from using LEV reported in the field survey data is largely in agreement with the 92.8% reduction of G_{APS} from using LEV from the laboratory test data.

The G_{APS} result for the PacTool 404 power shears was 0.0059 ± 0.0008 g/m at a cutting feed rate of 2.54 cm/sec, verifying that it is an almost dust-free operation. This result showed a 79.5% reduction compared to the G_{APS} of the C-M saw with LEV operating at an exhaust air flow rate of 2.54 m^3/min (~90 CFM). Compared to the C-M saw without LEV, the G_{APS} result for the PacTool 404 power shears showed a 98.5% reduction. Therefore, cutting fiber-cement siding using power shears similar to the PacTool 404 could be expected to result in exposures to respirable crystalline silica lower than those observed during the field surveys that used dust-collecting circular saws with LEV (0.013±0.009 mg/m^3) or without LEV (0.084±0.055 mg/m^3).

Conclusions/Recommendations

Controlling exposures to occupational hazards is the fundamental method of protecting workers. Traditionally, a hierarchy of controls has been used as a means of determining how to implement feasible and effective controls. One representation of the hierarchy of controls can be summarized as follows:

- Elimination
- Substitution
- Engineering Controls (e.g. ventilation)
- Administrative Controls (e.g. reduced work schedules)
- Personal Protective Equipment (PPE) (e.g. respirators)

The idea behind this hierarchy is that the control methods at the top of the list are potentially more effective, protective, and economical over time than those at the bottom. Following the hierarchy normally leads to the implementation of inherently safer systems, ones where the risk of illness or injury has been substantially reduced.

Comparing the results of the laboratory tests and field survey data reported previously suggest that the reduction of G_{APS} resulting from the use of LEV with dust-collecting circular saws in the laboratory tests is largely in agreement with the exposure reduction obtained during field surveys using this control measure. The significantly lower G_{APS} for the PacTool 404 power shears compared to that of the C-M saw with LEV indicated that cutting fiber-cement siding using power shears similar to PacTool 404 could be expected to result in 8-hr TWA exposures to respirable crystalline silica lower than those observed during construction site field surveys using dust collection circular saws with LEV (0.013±0.009 mg/m^3). From the perspective of exposure control, the use of this type of power shears is a preferred practice for cutting fiber-cement siding when practical, and this method adheres to the hierarchy of controls.

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