IN-DEPTH SURVEY REPORT OF CONTROL OF RESPIRABLE DUST AND CRYSTALLINE SILICA FROM BREAKING CONCRETE WITH A JACKHAMMER

at

Bishop Sanzari Companies
North Bergen, NJ

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REPORT DATE
February, 2003

REPORT NO
EPHB 282-11a

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SIC CODE	1611 (Highway and Street Construction)
SURVEY DATE	July 26, 2002
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DISCLAIMER

ABSTRACT

Three different dust controls for use with jackhammers were evaluated The objective of this study was to quantify the exposure reduction that could be achieved through the use of a water spray attachment and two different tool-mounted local exhaust ventilation shrouds during concrete pavement breaking with jackhammers The effectiveness of the dust controls examined in this study was evaluated by measuring the reduction in the respirable dust exposure in the breathing zone of the construction worker when a dust control device was used compared to the exposure when no dust control device was used Respirable dust exposure was measured in real time using a portable laser photometer In addition, personal breathing zone samples were collected and analyzed using established NIOSH methods Mean respirable dust concentrations when using water as a control were consistently statistically lower at the $p<0\ 05$ level from the means of all other types of controls, for both the personal breathing zone samples collected on filters and the real-time results Use of water, applied using a solid cone nozzle at a flow rate of 350 mL of water per minute, also resulted in the greatest reduction in respirable dust concentration when compared with no control (72% for filter samples and 90% for real-time samples) Both local exhaust ventilation controls showed reductions in the 50 to 60% range However, reductions using exhaust ventilation controls were not statistically significantly different from each other or from no control at the $p<0\ 05$ level due to the variability of the measurements made when exhaust ventilation controls were used

INTRODUCTION

The National Institute for Occupational Safety and Health (NIOSH) is located in the Centers for Disease Control and Prevention (CDC), under the Department of Health and Human Services (DHHS) NIOSH was established in 1970 by the Occupational Safety and Health Act, at the same time that the Occupational Safety and Health Administration (OSHA) was established in the Department of Labor (DOL) The OSH Act legislation mandated NIOSH to conduct research and education programs separate from the standard-setting and enforcement functions conducted by OSHA An important area of NIOSH research deals with methods for controlling occupational exposure to potential chemical and physical hazards

The Engineering and Physical Hazards Branch (EPHB) of the Division of Applied Research and Technology (DART) has been given the lead within NIOSH to study and develop engineering controls and assess their impact on reducing occupational illness Since 1976, EPHB (and its predecessor, the Engineering Control Technology Branch) has conducted a large number of studies to evaluate engineering control technology based upon industry, process, or control technique The objective of each of these studies has been to evaluate and document control techniques and to determine their effectiveness in reducing potential health hazards in an industry or for a specific process

The goal of this project was to quantify the exposure reduction that could be achieved through the use of a water spray attachment and two different tool-mounted local exhaust ventilation shrouds during concrete pavement breaking with jackhammers In this case, the water spray attachment consisted of a spray nozzle, of the type used with oil-burning furnaces, and associated hoses and fittings Water was supplied by a pressurized tank mounted on the air-compressor trailer The local exhaust ventilation (LEV) included an off-the-shelf shroud typically used with hand-held rock drills and a custom-made shroud The same dust collector, one sold for use with the rock-drill hood, was used for both LEV attachments

OCCUPATIONAL EXPOSURE TO CRYSTALLINE SILICA

Silicosis is an occupational respiratory disease caused by inhaling respirable crystalline silica dust 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 Exposure to respirable crystalline silica dust occurs in many occupations, including construction 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[1] The three major forms of crystalline silica are quartz, cristobalite, and tridymite[1] Quartz is the most common form of crystalline silica[1] Respirable refers to that portion of airborne crystalline silica that is capable of entering the gas-exchange regions of the lungs if inhaled, this includes particles with aerodynamic diameters less than approximately 10 µm[2]

When proper practices are not followed or controls are not maintained, respirable crystalline silica exposures can exceed the NIOSH Recommended Exposure Limit (REL), the OSHA Permissible Exposure Limit (PEL), or the American Conference of Governmental Industrial Hygienists (ACGIH) Threshold Limit Value (TLV).[2-4] NIOSH recommends an exposure limit of 0.05 mg/m^3 to reduce the risk of developing silicosis, lung cancer, and other adverse health effects.

The OSHA PEL for respirable dust containing 1% quartz or more is expressed as an equation:

$$\text{Respirable PEL} = \frac{10}{(\%\ \text{Silica}) + 2} \qquad (1)$$

If, for example, the dust contains no crystalline silica, the PEL is 5 mg/m^3, and if the dust is 100% crystalline silica, the PEL is 0.1 mg/m^3. For tridymite and cristobalite, OSHA uses half the value calculated using the formula for quartz. The ACGIH TLVs for cristobalite, quartz, and tridymite are all 0.05 mg/m^3.

METHODS

Exposure assessment

The effectiveness of the dust controls examined in this study was evaluated by measuring the reduction in the respirable dust exposure in the breathing zone of the construction worker when a dust control device was used compared to the exposure when no dust control device was used. Respirable dust exposure was measured in real time using a portable laser photometer (DUSTTRAK™ Aerosol Monitor, TSI Inc., St. Paul, MN) connected via flexible tubing to a respirable dust pre-selector (a nylon cyclone) placed in the employee's breathing zone. In addition, personal breathing zone samples were collected at a flow rate of 4.2 liters/minute using a battery-operated sampling pump at the employee's waist connected via Tygon tubing to a pre-weighed, 37-mm diameter, 5-micron (µm) pore-size polyvinyl chloride filter supported by a backup pad in a three-piece filter cassette sealed with a cellulose shrink band in accordance with NIOSH Methods 0600 and 7500, and a cyclone (GK 2.69 Respirable/Thoracic Cyclone, BGI Inc., Waltham, MA) placed in the employee's breathing zone.[5] In addition to the personal samples, bulk samples of settled dust were collected in accordance with NIOSH Method 7500. Bulk samples were collected from two of the sound barriers and two of the reinforced concrete pavement slabs shown in Figure 1. A bulk sample was collected from the bag at the outlet of the dust collector as well, representing a composite of the material that was chipped and collected.

Gravimetric analysis for respirable particulate was carried out with the following modifications to NIOSH Method 0600: 1) the filters and backup pads were stored in an environmentally controlled room (20±1 °C and 50±5% relative humidity) and were subjected to the room conditions for at least two hours for stabilization prior to tare and gross weighing, and, 2) two weighings of the tare weight and gross weight were performed [5] The difference between the average gross weight and the average tare weight was the result of the analysis The limit of detection for this method was 0 02 mg

Crystalline silica analysis of filter and bulk samples was performed using X-ray diffraction NIOSH Method 7500 was used with the following modifications 1) filters were dissolved in tetrahydrofuran rather than being ashed in a furnace, and, 2) standards and samples were run concurrently and an external calibration curve was prepared from the integrated intensities rather than using the suggested normalization procedure [5] These samples were analyzed for quartz and cristobalite The limits of detection for quartz and cristobalite on filters were 0 01 and 0 02 mg, respectively The limit of quantitation is 0 03 mg for both quartz and cristobalite The limits of detection in bulk samples were 0 8% for quartz and 1% for cristobalite The limit of quantitation was 2% for both forms of crystalline silica in bulk samples

Description of controls

This study evaluated the effectiveness of local exhaust ventilation and water spray controls Two different local exhaust ventilation controls were tested The first (Figure 2) was an off-the-shelf rock drill dust control shroud (Suction Hood PN 3214 2203 00, Atlas Copco Construction Mining Technique USA Inc , Commerce City, CO) This shroud is intended to lie flat on the work surface, while the bit of the pneumatic tool is inserted through the shroud into the work surface below The shroud is split to allow for easy insertion and removal of the bit Air is exhausted through a take-off in the side of the shroud, parallel to the plane of the work surface In order to prevent the shroud from climbing the jackhammer bit during use, a length of 4-inch-diameter corrugated black plastic drainage pipe was placed between the shroud and the jackhammer and secured with duct tape (Figure 3)

The second shroud (Figures 4 and 5) was designed and custom made for this project (Eurovac, Concord, Ontario, Canada) It consisted of a steel collar welded to a steel "U," that was in turn welded to two steel tangs that were attached to the jackhammer with the latch bolt A 7-inch length of 3-inch-diameter wire-wound clear flexible tubing was attached to the bottom of the collar with a hose clamp This tubing served as the inlet for the shroud The shroud was exhausted through a length of 1 5-inch-diameter steel tubing that was attached to the collar at a 90° angle, which was welded to another length of 1 5-inch steel tubing at a near 90° angle, with the opening (the vacuum hose attachment point) pointing up the barrel of the jackhammer, toward the handle A NIOSH technician welded a piece of flat steel plate across the top of the steel "U" to prevent air from entering the exhaust stream through that opening (Figure 6) The manufacturer recommended an exhaust flow rate of 100 cubic feet per minute (cfm) at 70 to 80 inches of water in order to effectively capture the dust [6]

The water spray attachment was fabricated by one of the contractors who participated in this study (Tilcon New York, Inc at their Mt Hope facility in Wharton, NJ) The water nozzle used was a solid cone nozzle of the type used for oil burners (Type B, 11 00 GPH, 80°, Delavan Inc

Fuel Metering Products, Bamberg, SC) It was mounted in a bracket welded on the end of the jackhammer and connected via flexible 16 pounds per square inch (psi) ⅜-inch-diameter hydraulic line to a quarter-turn valve mounted near the handle of the jackhammer A length of ⅜-inch-diameter air hose led from the valve to a 60-gallon water tank (pressurized to 22 psi) mounted on the air compressor trailer (Figures 7 and 8) The pressure in the tank was controlled by a regulator The contractor estimated that the cost for parts and machining was approximately $200 00 [7]

Experimental design

For the trials with the ventilation controls, 60-lb jackhammers (also known as pavement breakers) were used that were similar to the types typically used by the contractors with whom we worked on this project Due to a lack of communication among the partners, a 90-lb jackhammer was used for the trials with the water-spray control The ventilation control/jackhammer pairs were connected via flexible hose to a rock-drill dust collector (DCT-10, Atlas Copco Construction Mining Technique USA Inc , Commerce City, CO) The manufacturer reports that this unit has a maximum flow capacity of approximately 100 cfm at an operating pressure of 8 bar (116 psi) [8] At that flow rate, the maximum static pressure is reported to be approximately 450 millimeters of water (17 7 inches of water) [9] The jackhammers were used with 3-inch chisel bits for all trials, except for the first use of the water-spray control, where a standard moil point chisel was used For the trials where no control was used, the construction workers used the 60-lb jackhammer normally supplied by their employer

The aim of this study was to estimate the reduction in dust produced by the units with controls compared to that produced by those without controls Percent reduction was estimated by

$$\text{Estimated \% Reduction} = 100 \times [1 - (\text{control mean})/(\text{ no-control mean})] \qquad (2)$$

In order to measure this reduction, trials of the controls were conducted in 4 rounds consisting of 4 trials in each round The order of the trials was randomized within each round (see Figure 9) Each trial lasted approximately 10 minutes Real-time and filter samples were collected during each trial [Note A weld on the custom-made shroud broke after the third trial (Figure 10)]

Each trial consisted of using a jackhammer to break up a slab of reinforced concrete pavement or a concrete sound barrier (laid on its side) in the materials storage yard of the participating construction company (Figure 1) Two construction workers participated in the study Both workers wore hard hats, safety glasses, ear plugs, work gloves, work boots, and half-facepiece dual cartridge air-purifying respirators with P100 filters In addition, each wore a metal toe guard on one foot while operating the jackhammers

Wind and weather measurements

Wind direction and velocity were measured using an ultrasonic wind sensor (WindObserver II, Gill Instruments Ltd , Lymington, England) placed on a low wooden stand near (but not blocked by) the air compressor trailer The compressor's battery provided power to the system through a voltage inverter Temperature and relative humidity were recorded twice during the course of the day using a multi-parameter ventilation meter (VELOCICALC® Plus model 8386, TSI Inc , St Paul, MN)

Water flow measurements

Water flow through the spray nozzle was measured using a stopwatch and a measuring cup The stopwatch and water flow were started simultaneously and the amount of water dispensed in one minute was recorded Three measurements were performed in order to obtain an average flow rate

Statistical methods

All data were first tested for lognormality, and data were found to be lognormal Statistically significant differences in mean concentrations with various types of controls were determined using a one-way analysis of variance of the log-transformed data Bonferroni adjustments were done for comparisons between mean control levels

RESULTS AND DISCUSSION

Effect of controls on respirable dust exposures

Mean respirable dust concentrations when using water as a control were consistently statistically lower at the p<0 05 level from the means of all other types of controls, for both the personal breathing zone samples collected on filters and the real-time results Reductions using exhaust ventilation controls were not statistically significantly different from each other or from no control at the p<0 05 level due to the variability of the measurements made when exhaust ventilation controls were used Air sampling results from the filter samples are presented in Table 1 Real-time air sampling results are provided in Table 2

Use of water also resulted in the greatest reduction in respirable dust concentration when compared with no control (72% for air samples and 90% for real-time samples) Both shroud and vacuum controls showed reductions in the 50% to 60% range Percent reduction for each type of control is given in Table 3

Crystalline silica sampling results

Analysis of the sound barrier bulk samples indicated that they contained 19% quartz (by weight) The two samples of reinforced concrete pavement contained 23 and 28% quartz The sample from the dust collector contained 19% quartz

Three of the personal breathing zone samples were not analyzed for silica because the mass of respirable dust collected on the filter did not exceed the limit of quantitation for silica (0 03 mg for both quartz and cristobalite on filter samples) These samples were collected during the use of the water spray in rounds one and three, and during the use of the rock-drill shroud in round two Cristobalite was not detected on any of the filters (the limit of detection was 0 02 mg) Trace amounts of quartz, between the limit of detection and limit of quantitation, were found on three filters These were collected when no control was used in the third and fourth round, and when the custom-made hood was used in round three Quartz was not detected in the remaining personal breathing zone samples These results were due in part to the fact that the mass of respirable dust collected on all of the samples was low (<0 02 mg to 0 14 mg of respirable dust) Even if the dust in those samples contained 22% quartz, the average amount in the bulk samples (resulting in 0 004 mg to 0 03 mg of quartz on the filters), the mass of quartz on the filters would not have exceeded the limit of quantitation This illustrates one of the drawbacks of using short sampling times when evaluating controls

Wind and weather results

The average wind speed was 4 mph, with a maximum of 13 mph The prevailing wind was to the west (average bearing 90 degrees) The workers' positions in relation to the wind direction changed throughout the day, so no attempt was made to correlate wind speed with exposure However, based on observations of the airborne dust, the wind did not appear to hinder the effectiveness of the controls The temperature ranged from 71 to 73 °F, and the relative humidity ranged from 41 to 43%

Water flow results

The water spray attachment delivered approximately 350 mL of water per minute at the jackhammer This flow rate reduced dust by an average of 72 to 90% when compared to no control Water supplied at this flow rate did not add a substantial amount of water to the work surface In fact, the surface dried to the touch after the pavement breaking trial stopped Additionally, use of the water control device did not wet the workers' clothing or shoes

Conclusions and recommendations

This study demonstrated that a water spray control that used a readily available nozzle at a low flow rate was capable of achieving a 70 to 90% reduction in respirable dust exposures Two ventilation shrouds were capable of achieving reductions in the range of 50 to 60% Although these reductions were not significantly different from no control, they indicate that ventilation shrouds merit further investigation In addition, the dust collector selected for this evaluation did not operate within the parameters recommended by the maker of the custom-made shroud Thus, the custom-made shroud should be re-evaluated using a dust collector that is capable of producing a negative pressure in the range specified by the shroud manufacturer The fact that the shroud broke indicates that a more rugged design may be required, perhaps a cast piece rather than a welded shroud would suffice

Another limitation of this study is that a 90-lb jackhammer was used with the water spray control, while 60-lb jackhammers from three different manufacturers were used for the two LEV controls and the no-control condition The effect of the heavier hammer on the sampling results when compared to the lighter hammers is unknown Although the three 60-lb jackhammers were nearly identical in their appearance, the effect of using jackhammers from different manufacturers is not known The fact that the jackhammer used with the custom-made hammer was new at the time of the survey, while the other jackhammers were not, may have also introduced error

The water spray device was very effective in reducing respirable dust concentrations The current configuration consisted of one nozzle aimed at the front of the jackhammer chisel Additional designs should be constructed and tested, to determine if a different nozzle arrangement, flow rate, or nozzle type would result in better control

Full-shift sampling should be conducted using the water spray control to confirm its effectiveness during actual pavement breaking tasks This would also allow investigators to determine if point-of-operation visibility is hampered by this control Future versions of the water spray device may utilize pressurized water lines rather than a pressurized water tank

The benefits of the experimental design used in this study were reduced exposure to the worker and relatively quick assessment of controls, which were made possible through the use of a real-time aerosol instrument and the higher-flow cyclone The design also allowed the investigators to select the water-spray control for further evaluation in the field

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Table 1 Results of Personal Breathing Zone Samples for Respirable Dust Collected on Filters

Round	Trial	Description	Concentration (mg/m^3)	Geometric Mean (mg/m^3)	Geometric Std. Dev.
1	1	no control	1 45	2 06	1 53
2	5	no control	1 43		
3	10	no control	3 33		
4	14	no control	2 62		
1	2	water spray	0 23	0 55	1 87
2	7	water spray	0 90		
3	9	water spray	0 52		
4	15	water spray	0 83		
1	3	rock-drill shroud	0 76	0 87	1 42
2	6	rock-drill shroud	0 60		
3	12	rock-drill shroud	0 93		
4	13	rock-drill shroud	1 36		
1	4	custom-made shroud	1 26	1 12	1 33
2	8	custom-made shroud	1 38		
3	11	custom-made shroud	0 81		

Note A weld broke on the custom-made shroud after the third trial A fourth trial was not conducted with that control

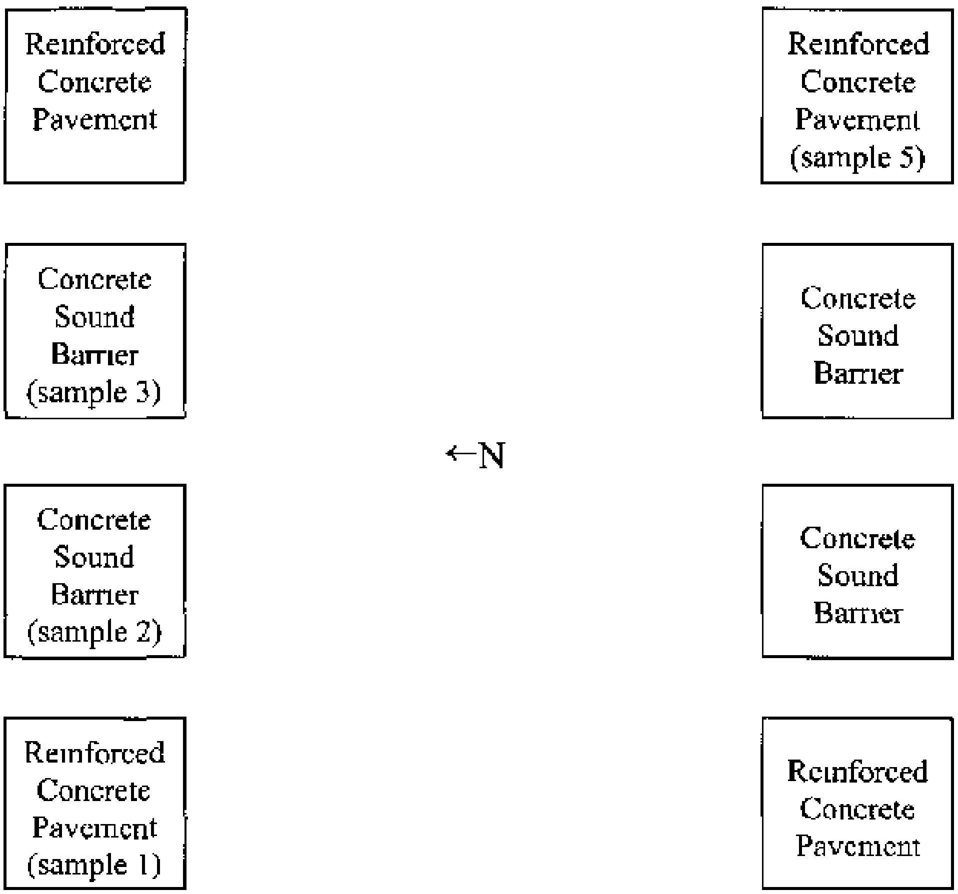
Table 2 Direct Reading Respirable Dust Results

Round	Trial	Description	N	Geometric Mean Concentration (mg/m³)	Geometric Std. Dev.	Minimum (mg/m³)	Median (mg/m³)	Maximum (mg/m³)
1	1	no control	758	0.38	6.52	0.01	0.39	27.16
2	5	no control	613	0.70	4.76	0.01	0.81	23.72
3	10	no control	611	1.35	4.39	0.02	1.69	36.91
4	14	no control	659	0.52	6.65	0.01	0.50	63.97
1	2	water spray	651	0.04	3.59	0.01	0.03	4.57
2	7	water spray	675	0.05	4.66	0.01	0.04	7.28
3	9	water spray	617	0.07	4.76	0.01	0.05	8.23
4	15	water spray	619	0.16	3.54	0.01	0.15	3.44
1	3	rock-drill shroud	595	0.45	3.02	0.01	0.49	5.32
2	6	rock-drill shroud	642	0.59	3.30	0.02	0.66	20.48
3	12	rock-drill shroud	607	0.52	3.40	0.02	0.51	27.77
4	13	rock-drill shroud	629	0.60	2.83	0.03	0.64	16.01
1	4	custom-made shroud	623	0.44	4.66	0.01	0.52	12.50
2	8	custom-made shroud	631	0.15	7.54	0.00	0.11	40.14
3	11	custom-made shroud	621	0.22	4.66	0.01	0.19	17.00

Note. A weld broke on the custom-made shroud after the third trial. A fourth trial was not conducted with that control.

Table 3   Reduction in Exposure for Each Control Versus No Control

Type of Sampling	Control	% Reduction
Respirable Dust on Filters	water spray	71 7
	rock-drill shroud	58 7
	custom-made shroud	47 9
Real-Time	water spray	90 1
	rock-drill shroud	57 3
	custom-made shroud	58 7



Note Sample 4 was collected from the bag attached to the dust collector

Figure 1 Layout of Concrete Slabs, Showing Bulk Sample Sources

Figure 2 The rock-drill shroud

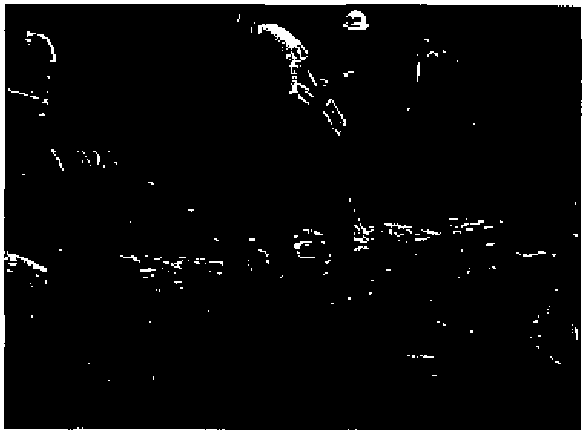


Figure 3 The rock-drill shroud in use

Figure 4 The custom-made shroud
Flexible tubing removed for clarity

Figure 5 The custom-made shroud in use The dust collector is in the foreground

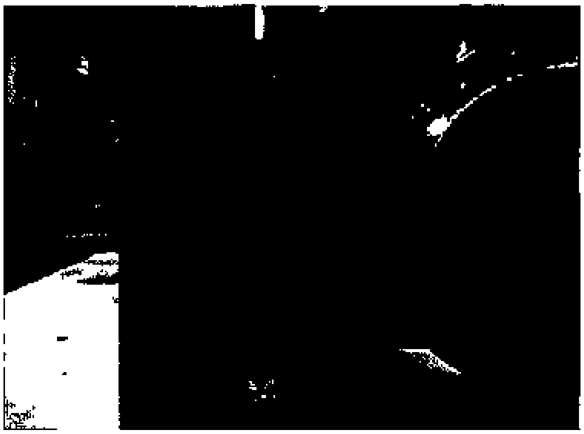


Figure 6 Plate welded across top of the U to block air from entering the hood View is from the bottom

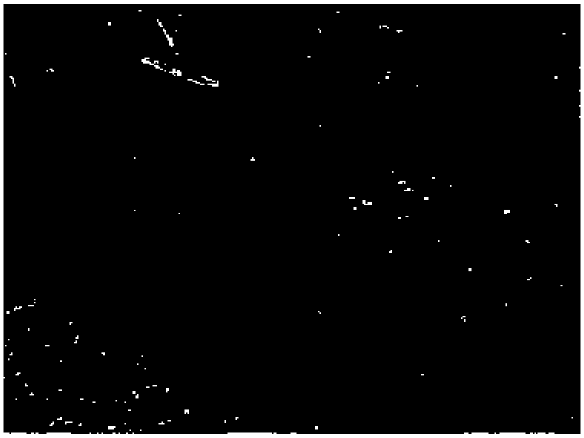


Figure 7 The water spray attachment, showing method used to attach the nozzle to the tool

Figure 8 The jackhammer with the water spray in use

Rounds	Trials			
1	1	2	3	4
	no control	water spray	rock-drill shroud	custom-made shroud
2	5	6	7	8
	no control	rock-drill shroud	water spray	custom-made shroud
3	9	10	11	12
	water spray	no control	custom-made shroud	rock-drill shroud
4	13	14	~~custom-made shroud~~	15
	rock-drill shroud	no control		water spray

Note X indicates that this trial was not run because a weld on the shroud broke

Figure 9 Four Rounds of Randomized Trials Used To Evaluate Dust Controls

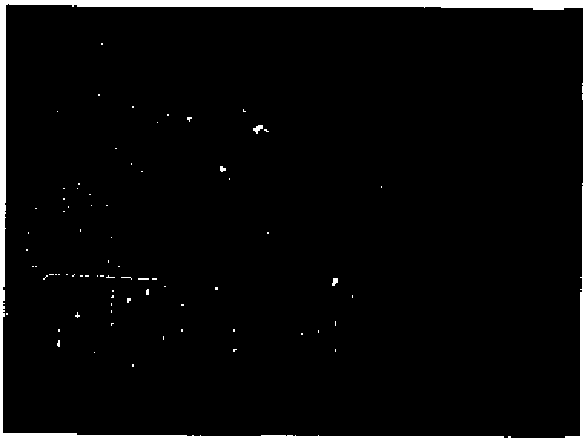


Figure 10 The broken weld on the custom-made shroud