The effectiveness of DustBubbles on dust control in the process of concrete drilling

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Abstract: Construction dust is one of the most concerned pollutants presenting risks to human health. Dust generated from concrete drilling, particularly true for silica dust, have an adverse effect on the health of workers. There is a long-term concern about the overexposure of construction workers to respirable crystalline silica. The high exposure to silica, even over a short period, can lead to silicosis. In order to control the dust generated during the process of concrete drilling, a local Hong Kong contractor has implemented DustBubble during the concrete drilling works. In order to evaluate the effectiveness of this new dust control measure, an experimental study has been designed and conducted. The respirable dust and silica dust concentrations of the following two situations were compared: workers drilling concrete with and without the use of DustBubble. Personal respirable samples were collected and analysed based on NIOSH 0600 and 7500 methods. The results revealed that DustBubble could significantly reduce the respirable dust exposure by 63%. However, there was no evidence that the use of DustBubble could reduce the respirable quartz exposure.

Keywords: DustBubble; Respirable dust; Respirable silica dust; Concrete drilling

1. Introduction

Dust is defined as all particulate matter up to 75 μm diameter according to BS6069 and comprising both suspended and deposited dust. Dust from construction activities, particularly true for silica dust, has an adverse effect on the local environment and on the health of local residents, as well as on those working on the site. There is a long-term concern about the overexposure of construction workers to respirable crystalline silica (Chisholm, 1999; Flanagan et al., 2003; Valiante et al., 2004). The high exposure to crystalline silica, even over a short period, can lead to silicosis.

More than 2 million workers are exposed to crystalline silica dust in the general, maritime, and construction industries (OSHA, 2003), and more than 100,000 workers have high-risk exposure to silica through construction and mining operations (Akbar-Khanzadeh and Brillhart, 2002). In Hong Kong, silicosis has been the most common occupational disease for the past several decades. According to Wong et al. (1995), up to 200 cases mostly from the construction industry are reported each year. Another report published by Occupational Safety and Health Branch (2010) indicated that around 100 new cases of silicosis were reported each year during the period of 2000 – 2009. What was worse, IARC recently classified crystalline silica as a class 1 carcinogen, which means that in IARC's opinion there was sufficient evidence for carcinogenicity in experimental animals and sufficient evidence for carcinogenicity in humans (IARC, 1997). Therefore, construction dust (especially crystalline silica dust) and its impact on local environment as well as health and safety have come into the focus of various concerned parties including workers, clients, contractors, and general public.

Many common construction activities, e.g. drilling, cutting, grinding etc., could generate high level of respirable dust and silica dust. Workers using rotary hammers or similar tools to drill small diameter holes in concrete, bricks, masonry blocks, tiles and similar materials can exposure to high levels of respirable silica dust if appropriate dust control measures are not taken (OSHA, 2009). A local Hong Kong contractor started using DustBubble at their sites to control dust when workers use electric hammers to drill small size holes in concrete walls. DustBubbles (DustBubble Ltd.) are disposable dust collectors for DIY or industrial drills. They use a combination of adhesion to the wall and the action of the drill itself to catch virtually all the dust during the drilling process. Pneumoconiosis Compensation Fund Board (PCFB) in Hong Kong, a statuary body established in 1980, initialed and funded this research to investigate its effectiveness on dust control and assess the viability of using it in Hong Kong. In order to achieve the above objectives, an experimental study has been designed and conducted to compare the dust exposures between two groups of workers: one group drilling the concrete without the use of DustBubble, the other with DustBubble. Two variables have been analysed and compared: respirable dust exposure and respirable silica dust exposure.

This paper first gives a short review of relevant literature, including silicosis and related respirable exposure limits for respirable dust and respirable silica dust. Then it turns to introduce how to use DustBubble, after which the experimental study and analysis methods are presented. Finally, the experimental results are listed and discussed.

2. Literature review

Excessive dust emissions can cause both health and industrial problems, e.g. health hazards, risk of dust explosions and fire, damage to equipment, impaired visibility, unpleasant odours and even problems in community relations. Excessive or long-term exposure to harmful respirable dusts may result in a respiratory disease called pneumoconiosis. This disease is caused by the buildup of mineral or metallic dust particles in the lungs and the tissue reaction to their presence. Silicosis is one of the most common pneumoconiosis in Hong Kong. According to the Annual report by PCFB (2011), there are 951 confirmed new cases of silicosis from 2000 to 2009, and 89% of cases have employment records in the construction/quarry industry.

2.1. Existing guidelines and limits for silica exposure

Silicosis, which is caused by the dust of quartz and other silicates, is irreversible, often progressive (even after exposure has ceased), and potentially fatal. In order to control the health hazard brought by dust, government and statutory bodies in Hong Kong and elsewhere have issued a number of regulations. Besides the regulations, a number of professional associations, e.g. the American Conference of Governmental Industrial Hygienists (ACGIH), National Institute of Occupational Safety and Health (NIOSH), have also adopted a number of standards, commonly known as Threshold Limit Values (TLVs), to evaluate the severity of health hazard in a workplace. These values are used as guides in the evaluation of health hazards. TLVs are time-weighted concentrations to which nearly all workers may be exposed 8 h per day over extended period of time without adverse effects. Table 1 lists the current US, UK and Hong Kong guidelines and limits for occupational exposure to crystalline silica.

When proper practices are not followed or controls are not maintained, respirable crystalline silica exposures can exceed the NIOSH Recommended Exposure Limit (REL), the Occupational Safety and Health Administration (OSHA) Permissible Exposure Limit (PEL), or the ACGIH Threshold Limit Value (TLV). The exceeded exposure could lead to silicosis. Therefore, it is very important to follow dust control practices in the construction industry.

Table 1
US, UK and Hong Kong guidelines and limits for occupational exposure to crystalline silica.

Reference	Substance	Guideline or limit (mg/m^3)
NIOSH (1977)	Crystalline silica: quartz, cristobalite and tridymite as respirable dust	REL = 0.05 (for up to a 10-h workday during a 40-h workweek)
OSHA (2003)	Dust (respirable) containing quartz dust (respirable) containing cristobalite dust (respirable) containing tridymite	8-h TWA PEL = 10 ÷ (%quartz + 2) PEL = half of the value calculated from the formula for dust-containing quartz
ACGIH (2008)	Respirable crystalline silica, quartz	8-h TWA TLV = 0.025
	Respirable crystalline silica, cristobalite	8-h TWA TLV = 0.025
	Respirable crystalline silica, tridymite	8-h TWA TLV = 0.025
GB-HSE (2005)	Respirable crystalline silica, total (quartz + cristobalite)	8-h TWA MEL = 0.1
Hong Kong Labour Department (1998)	Respirable dust, quartz	8-h TWA TLV = 0.1
	Respirable dust, cristobalite	8-h TWA TLV = 0.05
	Respirable dust, tridymite	8-h TWA TLV = 0.05
	Respirable dust, silica fused	8-h TWA TLV = 0.1
	Respirable dust, tripol	8-h TWA TLV = 0.1

Notes: CFR = Code of Federal Regulations; REL = recommended exposure limit; PEL = permissible exposure limit; TWA = time-weighted average; RDS = respirable dust standard; TLV = threshold limit value; MEL = maximum exposure limit.

Since this research was conducted in accordance with NIOSH 0600 and 7500, the TLV for silica issued by NIOSH, named as Recommended Exposure Limit (REL), was adopted as the test criteria: 0.05 mg/m^3 for an 8-h TWA (NIOSH, 2002). For the total respirable dust, the TLV issued by OHSA (Occupational Health and Safety Authority), named Permissible Exposure Limit (PEL), was taken as the test criteria: 5 mg/m^3 (for an 8-h TWA) for NIOSH has not published TLV for total respirable dust (OSHA, 2003).

2.2. Common dust control measures used in concrete drilling

In a survey reported by Chisholm (1999), four workers that conducted concrete drilling in concrete were monitored. No dust control measures were used and the respirable crystallized silica concentrations were 0.15 – 0.21 mg/m^3, which were well beyond the NIOSH limit of 0.05mg/m^3. In a case study reported by Lofgren (1993), three construction workers used pneumatic and electric drills with 3/4-in. bits to drill holes in the lower level of a concrete parking structure with poor ventilation. The employees used no dust control methods. The results showed that the silica exposure levels ranged from 0.1 mg/m^3 to 0.3 mg/m^3, which was 2 – 6 times the NIOSH recommended exposure limit of 0.05mg/m^3. Therefore, it is important to take appropriate measures to control dust during concrete drilling.

In order to reduce the high exposure levels, three primary methods exist: vacuum dust collection systems, wet methods and dust barriers (OSHA, 2009). Vacuum dust collection (VDC) systems are commercially available for handheld drills. Contractors could simply purchase appropriate systems for the workers; however, the authors did not find any contractors in Hong Kong using VDC systems during the process of concrete drilling. The cost of VDC systems should be one of the major concerns. Wet methods are normally used with pneumatic drills; however, they are normally inappropriate for electric rotary hammers that are used to drill small-size holes. Dust barriers refer to the technique to collect the dust generated from a single hole. It was reported that employees sometimes drill through shaving cream in an upside-down waxed paper cup or through a damp sponge to minimise exposure to asbestos (Woods, 2011). DustBubble is a new technique that belongs to the category of dust barriers, which is designed specifically for the drilling of small-size holes in concrete, slabs or tiles. The following section introduced the detailed procedures of using it to control dust.

3. The use of DustBubble

As shown in Fig. 1, according to the guidelines provided by DustBubble Ltd. (2011), there are four simple steps to use a DustBubble:

- Step 1: Rub the DustBubble between your fingers to loosen up the plastic, remove the backing tape and stick to the wall.
- Step 2: Pull the label to inflate the DustBubble.
- Step 3: Push the drill bit through the crosshairs on the label and drill, keeping the drill spinning on withdrawal.
- Step 4: Insert a wall plug through the DustBubble to seal the hold. To remove, wrap your fingers around the DustBubble and pinch carefully towards the hole.

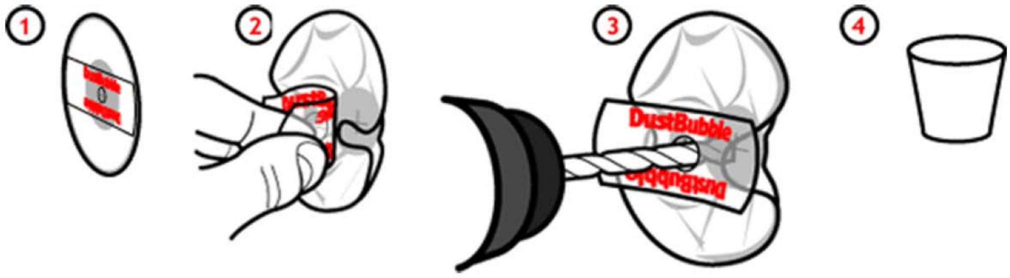

Fig. 1. Four steps of using DustBubble.

During the comparative experimental study, the following two situations were compared: (a) drilling concrete using electric rotary hammers with DustBubbles, and (b) drilling concrete using electric rotary hammers without DustBubbles. The worker using DustBubble were asked to follow the above four steps to conduct the drilling process.

4. Experimental methods

The main research methods taken during this experimental study were NIOSH 0600 and 7500 methods. Following these methods, personal respirable samples were collected and analysed to determine the respirable dust and silica dust exposure of workers during the process of concrete drilling.

4.1. Sampling methods

4.1.1. Personal respirable samples

Personal respirable dust samples were collected using pumps (GilAir-3) connected to 10 mm nylon cyclones, as shown in Fig. 2. Each set of sampling equipment was calibrated to a recommended flow rate of 1.7 l/min using an airflow calibrator. The sampling medium was a 37 mm, 5.0 µm pore size PVC filter, supported with backup pad in a two-piece cassette filter holder. This 10 mm nylon cyclone with its attachments was a light weight, size-selective particulate collector recommended by NIOSH (1998a,b).

Fig. 2. A worker wearing the sampling pump during the experimental study.

The duration of samples were determined by the limit of detection (LOD) parameters of laboratory analysis and the actual operational time of each work process/trade. From LOD perspective, the duration of samples should be longer enough for the laboratory analysis to detect the presence of silica, which gives the duration a lower duration limit (LDL). The LDL could be calculated by the following equation:

LDL= LOD/REL (NIOSH)/flow rate=118 min
(LOD: 0.01 mg, REL(Recommended exposure limit) by NIOSH: 0.05 mg/m^3; flow rate : 1.71/min)

Therefore, the duration of samples should be more than 118 min. In order to reduce the variability and narrow the confident limit, all the respirable samples during the study were taken for approximately 180 min. During the experimental study, trials of the block-drilling controls were conducted in two rounds consisting of 10 trials in each round. Total 20 samples have been collected with ten samples for each situation: with and without DustBubble. In addition to the personal respirable samples, other related variables were also collected and recorded, including filed blanks, and environmental variables.

4.1.2. Bulk samples

In order to determine the presence of silica and the relative percentage of different forms of silica (quartz, cristobalite, tridymite), settled dust was collected as bulk samples since the bulk sample should be representative of the airborne dust to which the workers are being exposed NIOSH (1998a,b).

4.1.3. Field blanks

Certain numbers of blank samples are required by NIOSH 0600 and 7500 methods: 2 – 10 per set (NIOSH 0600, 1998; NIOSH 7500, 2003). One field blank was taken for every ten samples gathered during the course of the project. The field blank cassettes were stored in the same conditions as the cassettes used for air sampling. The protocol used for acquiring field blanks consisted of: (1) opening the cassette, (2) attaching the cassette to the cyclone and sequentially to the sampling train, (3) allowing the cassette to collect dust passively (i.e. no pump operation) during a sampling period in the onsite sample and worker preparation area, and (4) returning the cassette to the sealed shipment bag with the other air samples. Therefore, the field blanks acted as quality control against potential contamination during preparation for sampling and shipment, as well as extended cassette exposure to ambient field conditions. Two filed blank were taken for the twenty samples during the study.

4.1.4. Environmental and other variables

Environmental variables, e.g. temperature, humidity, wind direction and velocity, will affect the dust exposures. In order to control the environmental variables, an indoor area was designed as the test area to minimise the effects of wind. The two workers (with or without DustBubble) started the drilling simultaneously to make sure they were conducted in the same environmental situations.

As a quality assurance, the environmental conditions were also measured using a 5-in-1 weather metre (MODEL: AZ 8910). Humidity, temperature, wind direction and velocity were recorded at the beginning, middle and end of each sampling processes. The results indicated that the environmental variables recorded for the paired samples were the same, which meant that the environmental variables need not be considered during the comparison.

During the experimental study, the workers' comments on the operation and effectiveness of DustBubbles were also collected to reflect the workers' perceived satisfaction towards the use of DustBubble.

4.2. Laboratory analysis

Two different analysis methods were used for personal samples and bulk samples. All analyses were conducted at the laboratory of Hong Kong Polytechnic University. The LOD and LOQ (limit of quantification) were 0.01 mg and 0.03 mg respectively.

4.2.1. Personal samples

All personal samples were firstly analysed for total weights according to NIOSH 0600 method using Mettler-Toledo XP 26 balance, which gave the concentration of total respirable dust. The samples were then analysed by X-ray following NIOSH 7500 method.

4.2.2. Bulk samples

A quick qualitative analysis on the bulk samples using X-ray in accordance with NIOSH 7500 method was conducted to determine the presence of silica and the relative levels of the three silica forms. If the presence of silica was confirmed and the major percentage of silica is quartz, the personal respirable samples collected during this experimental study were only analysed for quartz.

4.3. Testing materials and tools

Significant basis of this experimental study was the fact that all samples should be carried out under comparable conditions. In order to obtain reproducible results to compare drilling process with or without Dust Bubble, only a study in a test room was taken into consideration. With measurements taken at a real-life workplace, environmental impacts like air change rates, teat area sizes or changes in material mixtures can seldom be eliminated sufficiently. However, conditions of the experimental study should be set up as close as possible to those in practice. Therefore, all the materials used were kept the same as the practice.

It was estimated that it would take around 1 min for 1 hole when Dust Bubble was used. In order to make comparison, same number of holes should be drilled during the two drilling processes (with or without Dust Bubble). Therefore, a total of 180 holes were drilled for each 3-h sample. A 13 mm (in diameter) masonry drill was used for drilling. Each hole was around 3 cm deep into the block. The model of the hand drill was

Bosch GBH 2-20 D Professional (as shown in Fig. 3). A support as shown in Fig. 4 has been prepared to hold the testing material. The construction material (concrete block, C30) for treatment was placed vertically. The size of concrete block was 1 m ×1m×12 cm. The edge distance and interval distance between holes was 20 cm and 5 cm respectively so that 196 holes could be drilled on one side. Therefore, a total 392 holes could be achieved on both sides, which was enough for two samples. A number of 10 blocks were produced to achieve 20 samples.

Fig. 3. Electric hammer used in the study.

Fig. 4. A support for holding concrete blocks.

The assumption of this experimental study was that all the paired samples should be carried out under comparable conditions. In order to obtain reproducible results to compare drilling process with or without DustBubble, two samples were collected at the same time in the test area to eliminate the environmental impacts (e.g. wind, temperature, and material mixtures), as shown in Fig. 5. For each set of paired samples, the work load and duration were the same. The workers could take a 5-min break for every 20 min. Photos and video record have be taken during the experiment study.

Fig. 5. Drilling without DustBubble (left) and Drilling with DustBubble (right).

4.4. Statistical analysis

The main variables tested in this experimental study were total respirable dust concentrations and respirable quartz dust concentrations. The reduction in the two variables produced by the units with controls (DustBubble) compared to that produced by those without controls during concrete drilling processes were estimated through the following equation:

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

The data are generally assumed to follow the lognormal distribution, when samples are collected over time (NIOSH, 1977). Therefore, all the data has been tested firstly for a lognormal distribution. Descriptive statistics were used to describe total respirable dust and silica dust concentrations in terms of arithmetic and geometric means (AM and GM) as well as the corresponding geometric standard deviations (GSD) and ranges (min – max), while inferential statistics were conducted to compare the differences of dust generation between the two situations.

According to Hornung and Reed (1990), for the non-detectable values, there are two simple ways to reach enough accuracy: $1/\sqrt{2}$ of nondectable values when the data are not highly skewed; 1/2 of nondectable values when the data are highly skewed (Geometric Standard Deviation approximately 3.0 or greater). However, if more than half of one set of data are non-detectable, only the percentage of samples below LOD and the range of remaining samples were reported. Statistical analyses were conducted with SPSS statistical software (version 17; SPSS Inc.).

5. Results and discussions

Twenty personal samples and one bulk samples have been collected and tested. It was found that the bulk sample contained silica and 93% of silica existed as quartz. Therefore, only the quartz was tested during the X-ray analysis.

Twenty respirable samples have been collected and eighteen of them were valid. They show in Table 2, the results indicated that none of the measurements exceeded the exposure limits for the respirable dust concentration (5 mg/m^3) and seven samples exceeded the respirable quartz limit (0.05 mg/m^3). Since there are not more than half of respirable quartz concentration values (samples) that were below LOD, the non-detectable values were replaced as follows: LOD/($\sqrt{2}$ *volume) (since the GSD were less than 3).

The hypothesis of normal distribution could not be rejected for logarithmically transformed respirable dust ($p = 0.745 > 0.05$) and respirable quartz ($p = 0.236 > 0.05$) concentration values (Kolmogorov – Smirnov test), so the GM is a better way to describe the central tendency of lognormal distributions.

A non-parametric statistical comparison (Wilcoxon Test) was conducted to investigate whether there were significant differences between the respirable dust and respirable quartz dust concentrations of operators with DustBubble and without DustBubble. The results showed that there were significant differences between the exposure levels to total respirable dust ($p = 0.025 < 0.05$). The workers using DustBubble exposed to low level of respirable dust, which meant the use of DustBubble could reduce the respirable concentrations by 63% (GM: from 0.27 mg/m^3 to 0.10 mg/m^3; estimated reduction = (1- 0.09/0.29)×100% = 63%).

For respirable quartz dust, the estimated reduction of respirable quartz by DustBubble is 43% ((1-0.04/0.07)×100%). However, the results of statistical comparison indicated that there were no significant differences between the exposure levels to total respirable quartz dust ($p = 0.144 > 0.05$), which suggested that the use of Dust- Bubble could not significantly reduce the quartz exposure level of workers when drilling concrete. Moreover, both the GM of quartz concentration values of two groups (0.07 mg/m^3 and 0.04 mg/m^3 respectively) were over or close to the exposure limit, which suggested the concrete drilling process can generate high level of quartz dust and DustBubble is inadequate to protect workers. Other dust control measures (e.g. wet methods, and LEV) should be taken to reduce the quartz exposure level to below the limit. The workers should also wear appropriate respirators.

The workers using DustBubble were also interviewed to collect their feedbacks on the use of DustBubbles. They suggested that the use of DustBubble could reduce the dust generated for there was less settled dust or visible dust during the drilling with DustBubble (as shown in Fig. 6). However, it was commented that it is not so convenient to use DustBubble for there are several steps to prepare before the drilling. It was also claimed by the workers that it would take far much more time (normally two or three times longer than the normal duration) to finish drilling a hole, which may stop the contractors from using DustBubble. Sometimes, the DustBubble could not stick to the slab firmly during the drilling and dust was leaked out in that case.

Table 2
Experimental study-respirable dust and respirable quartz exposure.

	Respirable dust (mg/m^3)		Respirable quartz (mg/m^3)		Environmental variables[b]	
	Without DustBubble	With DustBubble	Without DustBubble	With DustBubble	Temp. (°C)	Humidity (%)
	1.86	0.10	0.02[a]	0.02[a]	23.8	66
	0.24	0.17	0.21	0.06	20.8	71.4
	0.22	0.14	0.06	0.03[a]	20.6	72.8
	0.15	0.14	0.09	0.09	16	53.8
	0.52	0.07	0.03[a]	0.03[a]	15.3	46.9
	0.59	0.21	0.48	0.03[a]	15	40.5
	0.20	0.03	0.03[a]	0.03[a]	16.9	56.9
	0.03	0.06	0.03[a]	0.05	21.1	74.4
Mean	0.48	0.11	0.12	0.05		
Geometric mean (GM)	0.27	0.10	0.07	0.04		
	$p = 0.025$		$p = 0.144$			

[a] Samples below LOD.
[b] Indoor area, no wind was record.

Fig. 6. Settled dust: without DustBubble (left) and with DustBubble (right).

6. Limitations

The major limitation of this research is that only one commonly used tool was tested. The use of DustBubble with other types of electric rotary hammers should be investigated. The size of drill bits is another issue. Normally, the larger the size of drill bits, the more dust it will generate. This research only tested the effectiveness of DustBubble with a certain size of hammer, so the links between the drill bit size and effectiveness of DustBubble remains unknown and should be worthy investigating.

Another limitation is the number of samples. Only 20 samples have been collected and analysed, more experimental studies should be conducted to collect more samples.

7. Conclusions

In this paper, an experimental study was presented which aimed to investigate the effectiveness of using DustBubbles in reducing the dust generated in concrete drilling processes using electric hammers for small-size holes. Personal respirable samples were collected and analysed for two situations: workers drilling with DustBubble, and workers drilling without DustBubble. The respirable dust concentrations and respirable quartz concentrations were compared. The results revealed that the use of Dust Bubble could reduce the respirable dust concentrations by 63%. However, there was no evidence that the use of Dust Bubble could reduce the respirable quartz exposure. Dust Bubble alone is inadequate and other dust control measures (e.g. wet methods, LEV and PPEs) should be taken to reduce the quartz exposure level to below the exposure limit. Since DustBubble could reduce the respirable dust significantly, further research should be conducted to further evaluate and improve the effectiveness of DustBubbles (especially on respirable silica dust).

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