



Respirable Crystalline Silica Exposure among Concrete Finishing Workers at Apartment Complex Construction Sites

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ABSTRACT

The objective of this study was to evaluate the level of exposure to respirable crystalline silica (RCS) among concrete finishers and to identify the size distribution of particles from concrete finishing work at apartment complex construction sites.

Active personal air sampling ($n = 129$) was conducted at eight sites using filters with aluminum cyclones, and local air sampling for the size distribution of the particles ($n = 6$) was conducted using a Mylar substrate with cascade impactors. Crystalline silica was analyzed by Fourier-transform infrared spectroscopy (FT-IR). The collected personal samples were sorted by the type of task (concrete chipping, grinding, or plastering) for four kinds of working places (exterior walls, interior walls of apartment units, staircases, and underground parking lots).

The geometric mean (GM) of the RCS concentration was highest, although varying according to the type of structure, for concrete grinding (2.06 mg m^{-3}), followed by chipping (0.12 mg m^{-3}) and plastering (0.003 mg m^{-3}). The maximum RCS concentration was measured in the staircases (4.18 mg m^{-3}), followed by the interior walls of apartment units (2.76 mg m^{-3}), underground parking lots (1.30 mg m^{-3}), and exterior walls (0.89 mg m^{-3}). The mass fraction of inhalable, thoracic, and respirable crystalline silica was respectively 73.9%, 40.2%, and 17.9% in chipping and 76.0%, 46.3%, and 19.7% in grinding.

Concrete finishing workers at apartment complex construction sites are exposed to unacceptably high concentrations of RCS. To protect workers' health, dust-minimizing construction methods as well as high-efficiency respirators paired with local exhaust ventilation systems or wet methods must be employed. Further efforts to reduce the total working time and to use full-faced air-purifying respirators are required.

Keywords: Construction workers; Concrete finishing; Respirable dust; Crystalline silica.

INTRODUCTION

Crystalline silica is a basic component of soil, sand, stones, and many other minerals that are the most frequently used materials at construction sites (Beaudry *et al.*, 2013). The hazards of silica were recognized from tunnel excavation and mining in 1930, but recently have been broadly recognized in the construction industry (Sauvé, 2015). Most construction workers are exposed to respirable crystalline silica (RCS) by performing tasks that generate RCS or through diffused dusty air containing RCS (Flanagan *et al.*, 2003; Sauvé *et al.*, 2013; Oude *et al.*, 2014). The tasks that generate large amounts of RCS at construction sites are concrete grinding, drilling, cutting and chipping, block and brick cutting,

removing mortar between bricks, cutting rocks, and ballasting structures (Flanagan *et al.*, 2003; Rappaport *et al.*, 2003; Tjoe Nij *et al.*, 2003; Sauvé *et al.*, 2013; Oude *et al.*, 2014). Many studies have reported that the concentration of RCS exceeded the occupational exposure limits in various construction jobs including concrete workers, such as recess millers, tuck pointers, and bricklayers; demolition workers; laborers; operating engineers; and even construction cleaners (Lumens and Spee, 2001; Rappaport *et al.*, 2003; Tjoe Nij *et al.*, 2003).

Crystalline silica is defined as a Group 1 carcinogen by the International Agency for Research on Cancer (IARC) (IARC, 2012) and has been associated with lung cancer, silicosis, kidney failure, and lung impairment. Silicosis has no standardized treatment method, so the most effective method is to minimize workers' exposure to prevent any related diseases (NIOSH, 2002). Surveys have indicated that there are about three million workers exposed to crystalline silica in the European Union (EU), 1.7 million in the United States, and 350,000 in Canada (Sauvé *et al.*, 2013). In

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Britain, most workers exposed to silica are construction workers and over half of the lung cancer deaths in men in 2004 were attributable to work in the construction industry (Rushton *et al.*, 2008).

Although some levels of silica exposure from construction activities have been reported, additional exposure assessment studies are needed because diverse environmental factors can affect the concentrations (Sauvé *et al.*, 2013), as can the characteristics of the ever-changing construction site work environments (Akbar-Khanzadeh *et al.*, 2002).

South Korea has a unique style of housing. That is, more than 60% of all houses are concrete apartments and apartment complexes, usually comprised of hundreds of households together in one area. In such a construction environment, large-scale concrete finishing work is carried out, but the levels of RCS exposure among concrete finishers have not been studied yet.

The objective of this study was to evaluate the exposure levels and size distribution of RCS among concrete finishers at the large-scale apartment complex construction sites.

METHODS

Exposure Group Selection and Task Description

Eight new apartment complex construction sites (Table 1) were selected to assess the concentration of respirable dust (RD) and RCS during concrete chipping, grinding, and plastering work between March and June in 2016. Concrete chipping (Fig. 1(a)) refers to using a hammer drill to cut off uneven concrete walls after removing the molding used to cure the concrete. Concrete grinding (Fig. 1(b)) is the use of a grinder to level a concrete surface after removing the molding. The grinder used for this study included a 4-in. industrial diamond wheel. Plastering work (Fig. 1(c)) involved mixing cement, sand, and water for application to the surface of concrete or brick walls to improve their aesthetic appearance.

A total of 36 workers participated in this study. They were examined for 3 consecutive days. Prior to each sampling, the workers were briefed on the purpose and method of sampling by our research staff and occupational health managers at their construction sites. Workers who volunteered for sampling wore RD and RCS samplers and informed consent was obtained verbally. We did not collect any personal information (name, gender, or age) when we received consent from the study participants. All participants in this study

were adults. The research results are presented by mean, variance, and range according to job type.

To analyze the concentration of RD and RCS, 129 breathing zone personal samples (Table 1) were collected to represent each concrete finishing work hazard concentration. The samples were collected during work hours and several samples (up to 4 samples day⁻¹) were collected from a single worker when processes changed during the day or the measured concentration was high. The sample collection times ranged from 55 to 523 minutes per sample. To identify the size distribution of crystalline silica, 6 cascade impactor samples were collected at Construction Site G during work hours for 2 consecutive days and the sample collection times ranged from 210 to 912 minutes per sample.

Sampling and Analysis

Sampling

Respirable dust was collected on gravimetrically analyzed polyvinyl chloride (PVC) filters (37-mm diameter, 5- μ m pores; SKC, Inc., USA) mounted on an aluminum cyclone (SKC, Inc., USA) connected to a pump (Escort Elf Sampling Pump; MSA, USA) with a flow rate of 2.5 L min⁻¹. The pumps were pre- and post-calibrated using a bubble calibrator (standard flow: 20 ccs to 6 L min⁻¹; Gillian Corp., USA).

Gravimetric Analysis of Dust

For the gravimetric analysis of dust, PVC filters were dried in a desiccator for over a day before sampling, stabilized in the gravimetric analysis chamber for > 2 h, and weighed three times using an electronic balance with 10⁻⁷ g readability (XP2U; Mettler Toledo, Switzerland) to calculate the mean value. The samples and blanks were dried, weighed, and calculated same as pre-filters.

Crystalline Silica Analysis

Crystalline silica was analyzed using Fourier-transform infrared spectroscopy (FT-IR) in accordance with the NIOSH Manual of Analytical Methods (NMAM) of the U.S. National Institute of Occupational Safety and Health (NIOSH) #7602 (NIOSH, 2003). To pre-treat the samples, the filter was placed in a jar and heated for 2 h in an electrical furnace set at 600°C. Potassium bromide (KBr; 300 mg) (FT-IR grade; Sigma-Aldrich) was added to the jar containing the filter ashes, mixed, and pressed in a 13-mm pellet die to make pellets. FT-IR (FT/IR-4600; JASCO, Japan) was used to

Table 1. Target monitoring of working place and number of samples.

No.	Site	No. of households	Sampling days	No. of workers	Average sampling time (min; (range))	No. of active personal samples (n)			
						Chipping	Grinding	Plastering	Sum
1	A	1,665	3	4	178 (65–320)	3	18	-	21
2	B	520	3	3	204 (100–516)	3	6	-	9
3	C	1,103	3	3	250 (151–298)	-	2	3	5
4	D	728	3	5	261 (55–501)	8	8	7	23
5	E	761	3	3	267 (160–480)	10	2	3	15
6	F	995	3	9	319 (61–523)	-	8	16	24
7	G	1,730	3	5	304 (197–500)	10	2	6	18
8	H	450	3	4	279 (201–486)	2	12	-	14
Sum						36	58	35	129

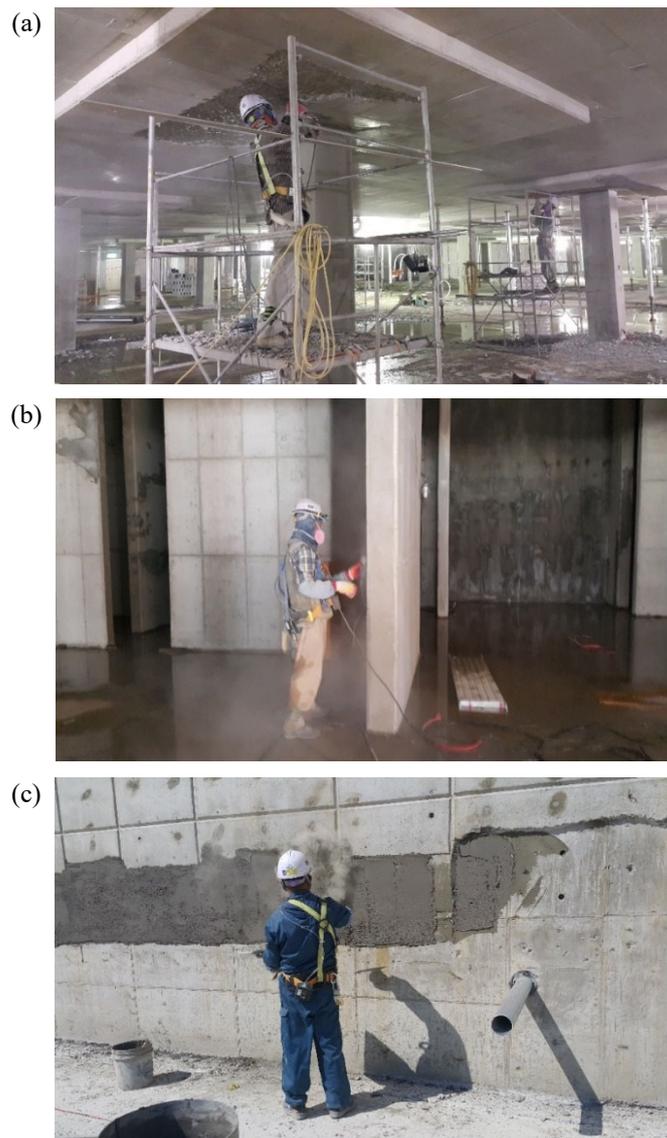


Fig. 1. Concrete (a) chipping, (b) grinding, and (c) plastering work.

measure the sample's absorbance at $600\text{--}900\text{ cm}^{-1}$ vibrations and the absorbance at 800 cm^{-1} vibrations was used to calculate the results. The calibration curve was created from 0.8 to $500\text{ }\mu\text{g}$ using SRM1878a respirable alpha quartz from the National Institute of Standards and Technology (NIST) as the standard. If it was not possible to form pellets because there was too much dust or the amount of quartz exceeded the range of the calibration curve, a portion of the dust was separated to determine the ratio of the dust sample weight to the weight of the total amount of dust. The limit of detection (LOD) was $1.4882\text{ }\mu\text{g}$ per sample. The amount of crystalline silica in all samples exceeded the LOD.

Analysis of Particle Size Distribution

In order to measure the size of dust, a Personal Cascade Impactor (Model 298; Andersen Samplers, Inc., USA) composed of an eight-stage impact plate was used. Mylar substrate (34-mm, 6-slot; TE-290-MY; Tisch Environmental, USA), the sample medium used to collect the dust particles,

was coated with silicone lubricant (3M, USA) and dried before attaching it onto the eight-stage impact plate. This prevented the loss of dust particles by particle bounce (Vaughan, 1989). In the last stage, a PVC ($5\text{-}\mu\text{m}$ pore size) filter was installed to even the flow of air. The flow was set at about 2 L min^{-1} to prevent particle bounce and loss from internal impacts at high flow and to prevent loss from internal accumulation at low flow.

The dust collected at each stage was assessed using gravimetric analysis and crystalline silica analysis. To calculate the mass median aerodynamic diameter (MMAD) of dust, the weight of dust from each stage was corrected by dividing it by the effectiveness suggested by the sampler manufacturer as the correction factor for the efficiency and internal loss of samples (Andersen Samplers, Inc., 1982). The corrected weight of dust was used to calculate the mass fraction (%) of each stage (Tables S1–S2). To calculate the mass fraction of dust for each dust particle size, the American Conference of Governmental Industrial Hygienists (ACGIH)

Particle Size-Selective Sampling Criteria for Airborne Particulate Matter was used (Bello *et al.*, 2002). In this study, particle sizes were expressed as inhalable particulate matter (hazardous when deposited anywhere in the respiratory tract), thoracic particulate matter (hazardous when deposited anywhere within the lung airways and the gas-exchange region), and respirable particulate matter (hazardous when deposited in the gas-exchange region) (ACGIH, 2013).

Statistical Analysis

The results were tested for normality of resources to examine the characteristics of distribution using the Shapiro-Wilk test and the data showed a log-normal distribution except for the RD concentration during plastering. The geometric mean (GM) and geometric standard deviation (GSD) were used to explain the concentrations by job types and working places. ANOVA and Pearson correlation analysis with log-transformed data were conducted to compare the mean exposure concentration for each job type and each working place and to assess the relationship between respirable crystalline silica and respirable dust concentrations. Multiple linear regression analysis was performed to identify the exposure determinants affecting the RD and RCS levels. The variables included in the multiple regression model were types of jobs, working places, and sampling (working) time. The types of jobs and working places were nominal variables, so they were converted into dummy variables. Statistical analyses were performed using PASW version 18.0 (SPSS Inc.; Chicago, IL, USA). The figures in this study were generated using Sigma Plot version 13.5 (Systat Software, Inc.; San Jose, CA, USA).

RESULTS AND DISCUSSION

RD and RCS in Concrete Finishing by Job Type

The personal exposure to RD and RCS from concrete chipping, grinding, and plastering work at construction sites is shown in Table 2. The concentrations of RD and RCS were significantly different between job types ($p < 0.001$). The GM of RCS exposure from concrete grinding work was 2.06 mg m^{-3} ($0.10\text{--}17.62 \text{ mg m}^{-3}$), which exceeded the Korean Occupational Exposure Limit (KOEL; 0.05 mg m^{-3} , which is the same as the U.S. Occupational Safety and Health Administration’s permissible exposure limits) by 41.2 times, based on an 8-hour work shift (Fig. 2). In addition, the GM of RCS exposure from concrete grinding work was more than 80 times the ACGIH threshold limit value (TLV) for crystalline silica (0.025 mg m^{-3}). All samples exceeded the exposure limits of 0.05 mg m^{-3} . The GM of RCS exposure from concrete chipping was 0.123 mg m^{-3} ($0.005\text{--}3.06 \text{ mg m}^{-3}$) and 75% of the samples (27/36) exceeded 0.05 mg m^{-3} . The GM of RCS exposure from plastering work was 0.003 mg m^{-3} (ND to 0.027 mg m^{-3}) and no sample exceeded 0.05 mg m^{-3} . The GM of RD exposure from concrete grinding was 49.96 mg m^{-3} ($4.26\text{--}367.58 \text{ mg m}^{-3}$), which exceeded the ACGIH’s TLV for general dust (respirable particles not otherwise specified) of 3 mg m^{-3} by about 16.6 times. The exposure to concrete chipping workers was 1.78 mg m^{-3} ($0.19\text{--}62.72 \text{ mg m}^{-3}$) and

Table 2. Respirable dust and respirable crystalline silica concentrations (mg m^{-3}) by type of concrete finishing work.

Job	No. of sample	Respirable dust				Respirable crystalline silica					
		Normality test (Shapiro-Wilk)	AM \pm SD	GM (GSD)	Range	Exc fra (%)	Normality test (Shapiro-Wilk)	AM \pm SD	GM (GSD)	Range	Exc fra (%)
Concrete chipping	36	Log-normal (p = 0.088)	4.55 \pm 11.07	1.78 (3.26)	0.19–62.72	27.70% (10/36)	Log-normal (p = 0.905)	0.32 \pm 0.60	0.12 (4.13)	0.005–3.06	75% (27/36)
Concrete grinding	58	Log-normal (p = 0.183)	78.6 \pm 76.56	49.96 (2.84)	4.26–367.58	100% (58/58)	Log-normal (p = 0.095)	3.54 \pm 3.67	2.06 (3.23)	0.1–17.62	100% (58/58)
Plastering	35	- (p < 0.001)	0.42 \pm 0.22	0.32 (2.87)	0.002–1.07	0% (0/35)	Log-normal (p = 0.894)	0.006 \pm 0.006	0.003 (2.86)	ND–0.027	0% (0/35)
ANOVA analysis											p < 0.001

※AM: arithmetic mean; SD: standard deviation; GM: geometric mean; GSD: geometric standard deviation; Exc fra: exceeding fraction (%); exceeding fraction of the occupational exposure limit of respirable dust (3 mg m^{-3}) and respirable crystalline silica (0.05 mg m^{-3}); ND: not detected.

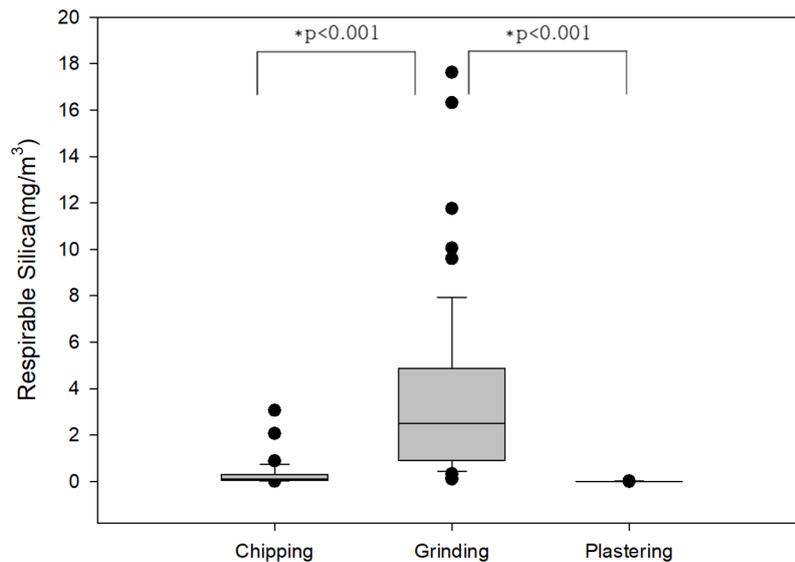


Fig. 2. Respirable crystalline silica exposure concentration by concrete finishing job. The boxes show the 25th and 75th percentiles and whiskers indicate 10th and 90th percentiles. Median is indicated by the line inside the box. Post hoc analysis was conducted by the Scheffe method ($p < 0.001$; chipping vs. grinding and grinding vs. plastering).

0.32 mg m⁻³ (0.002–1.07 mg m⁻³) for plastering work. All samples exceeded 3 mg m⁻³ in concrete grinding and 27.7% (10/36) of the concrete chipping worker samples exceeded 3 mg m⁻³.

RD and RCS in Concrete Finishing by Type of Working Place

The concentrations of RD and RCS were significantly different in concrete grinding and plastering work settings ($p < 0.05$), but not in chipping work settings ($p > 0.5$). Evaluation of the concentrations of RCS in each concrete grinding working place showed that the GM was highest in

a staircase at 4.18 mg m⁻³ (range: 0.49–17.62 mg m⁻³) (Fig. 3 and Table 3). The GM was 2.76 mg m⁻³ (range: 0.45–7.75 mg m⁻³) inside the apartment units, 1.30 mg m⁻³ (range: 0.10–5.16 mg m⁻³) in the underground parking lots, and 0.89 mg m⁻³ (range: 0.14–1.85 mg m⁻³) at the exterior walls. Evaluation of the concentrations of respirable dust at each concrete grinding working place showed that the GM was 95.54 mg m⁻³ (range: 10.45–367.58 mg m⁻³) in the staircases, 38.73 mg m⁻³ (range: 5.94–131.2 mg m⁻³) in the apartment units, 39.98 mg m⁻³ (range: 4.26–250.99 mg m⁻³) in the underground parking lots, and 27.22 mg m⁻³ (range: 0.10–5.16 mg m⁻³) at the exterior walls.

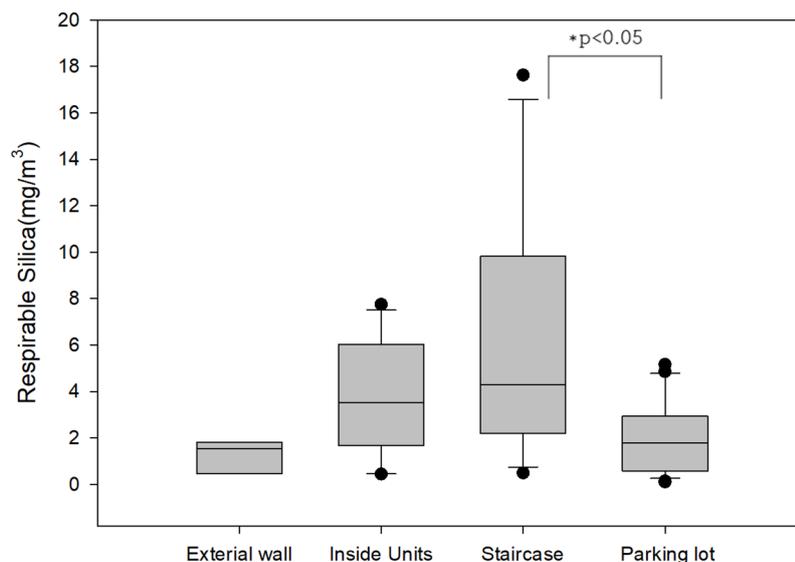


Fig. 3. Respirable crystalline silica exposure concentration of concrete grinding work by working place. The boxes show the 25th and 75th percentiles and whiskers indicate 10th and 90th percentiles. Median is indicated by the line inside the box. Post hoc analysis was conducted by the Scheffe method ($p < 0.05$; stairway vs. underground).

Table 4. Multiple regression analysis of RD and RCS by job type and working place. (Reference: job [plastering], working place [exterior wall], company [h])

	RCS		RD	
	B	β	B	β
Intercept	-4.653		-0.720	
Job (grinding)	5.766	0.990***	4.571	0.970***
Job (chipping)	3.332	0.516***	1.531	0.293***
Working place (staircase)	0.536	0.064	0.810	0.120*
Working place (inside apartment unit)	-0.272	-0.044	0.294	0.058
Working place (underground parking lot)	-0.256	-0.044	-0.046	-0.010
Sampling time	-0.002	-0.083	-0.001	-0.057
Adjusted R ²	0.841		0.842	
Durbin-Watson	1.778		1.824	
F	107.338***		108.147***	

* $p < 0.05$, *** $p < 0.001$.

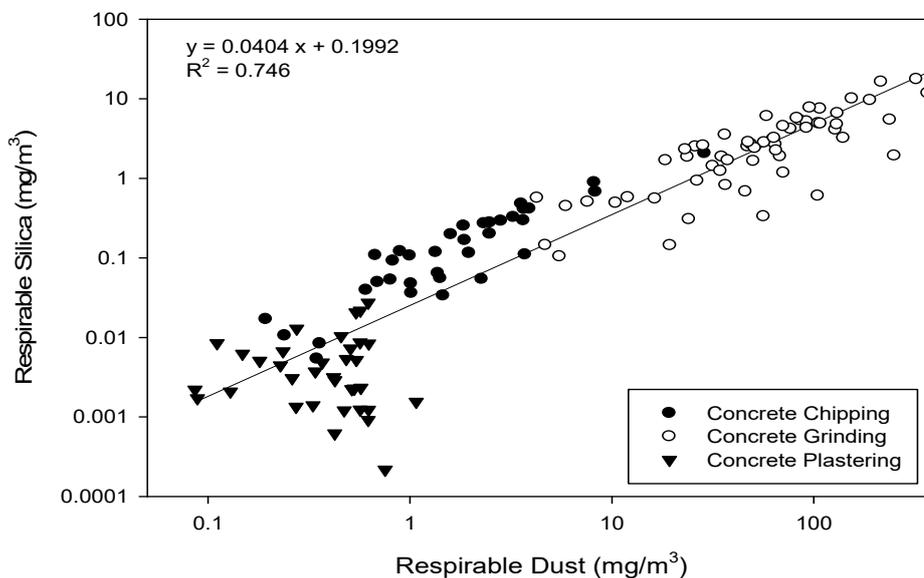
RD: respirable dust; RCS: respirable crystalline silica.

Table 5. Crystalline silica proportion (%) of sampled dust in each job type.

Job	n	Crystalline silica proportion (%)		Correlation b/w silica and dust (Pearson correlation factor)
		AM \pm SD	GM (GSD)	
Concrete chipping	36	8.00 \pm 3.80	6.92 (1.81)	0.970*
Concrete grinding	58	5.00 \pm 2.72	4.12 (2.03)	0.793*
Plastering	35	1.70 \pm 1.71	0.94 (3.52)	0.100
Total	129	4.94 \pm 3.68	3.19 (3.19)	0.864*

* $p < 0.01$.

AM: arithmetic mean; SD: standard deviation; GM: geometric mean; GSD: geometric standard deviation.

**Fig. 4.** Respirable dust and silica concentration by concrete finishing job type.

GM of RCS concentrations was highest in concrete grinding (2.06 mg m^{-3}), followed by concrete chipping (0.12 mg m^{-3}) and plastering work (0.003 mg m^{-3}). The GM of RCS concentrations present during concrete grinding work differed by the type of working place, with the highest concentration of RCS in staircases (4.18 mg m^{-3}), followed by the inside walls of apartment units (2.76 mg m^{-3}), underground parking lots (1.30 mg m^{-3}), and exterior walls (0.89 mg m^{-3}).

Furthermore, the concentration was statistically different according to the type of job. Previous studies have reported (Table S5) GM concentrations of 0.7 mg m^{-3} and 0.42 mg m^{-3} for a recess miller (Lumens and Spee, 2001; Tjoe *et al.*, 2003), 0.63 mg m^{-3} for a surface grinder (Flanagan *et al.*, 2003), 0.07 mg m^{-3} for a concrete floor sander (Flanagan *et al.*, 2003), and 1.28 mg m^{-3} (median value) for a painter blaster (Rappaport *et al.*, 2003). In this study, the GM of RCS was

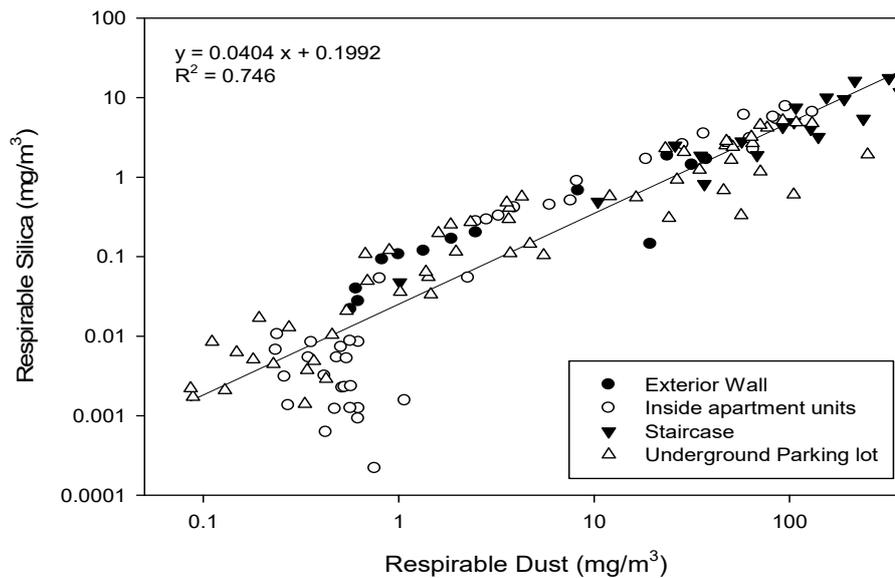


Fig. 5. Respirable dust and silica concentration by working place type.

Table 6. ACGIH particle size-selective fraction (%) of eight-stage cascade impactors in concrete chipping and grinding work.

Methods	Job	n	ACGIH particle size-selective fraction (%)		
			Inhalable	Thoracic	Respirable
By dust concentration	Concrete chipping	3	67.4	23.0	6.5
	Concrete grinding	3	68.7	26.6	7.9
By silica concentration	Concrete chipping	3	73.9	40.2	17.9
	Concrete grinding	3	76.0	46.3	19.7

Tables S1–S2 present the summary of raw data.

much higher than that reported in previous studies. We assume that the reason was due to the unique housing style of Korea, which consists of large-scale apartment complexes made of concrete and each apartment unit consists of several small rooms. Specifically, in concrete grinding work, where a concrete face is polished by more than 10,000 rpm (revolutions per minute) using an industrial diamond wheel, much higher concentrations of RCS are generated compared to chipping and plastering.

The concrete-dust control methods utilized so far include covering the grinding wheel with a ventilation cap and connecting it to a vacuum dust collector (Akbar-Khanzadeh *et al.*, 2007; Meeker *et al.*, 2009; Akbar-Khanzadeh *et al.*, 2010), the wet method (Beamer *et al.*, 2005; Meeker *et al.*, 2009; Healy *et al.*, 2014), and wearing respirators.

Akbar-Khanzadel *et al.* (2010) reported that the concentration of RCS measured during concrete grinding was highly affected by the efficiency of ventilation, the diameter of the grinder, and the use of local exhaust ventilation (LEV) systems. The study reported that general ventilation was 66% efficient in controlling RCS, LEV systems were 98–99% efficient, and wet grinding was 94% efficient. Healy *et al.* (2014) also compared the concentrations of RCS measured during the use of four types of concrete grinder covers currently used at construction sites. The concentrations of RD and RCS were significantly lower

when a cover was used compared to when no cover was used. The concentration of RD was 7.1 mg m^{-3} when no cover was used but was reduced by about 92% to 0.5 mg m^{-3} when a cover was used.

Beamer *et al.* (2005) applied various wet engineering methods to reduce the concentration of RCS from brick chipping and concluded that the moisture mist method was highly efficient and suitable for application at construction sites. Moreover, the moisture dries rapidly on the sprayed surface, preventing slipping and falling on wet surfaces in the working place.

Although the LEV systems and the wet method showed significant reductions in concentrations and workers wore half-mask respirators, some workers were still overexposed to RCS (Middaugh *et al.*, 2012). In the construction of large-scale apartment complexes, the GM of RCS was over 2 mg m^{-3} and, even though the reduction efficiency was 95%, the reduced concentration was still 0.1 mg m^{-3} , which exceeds the KOEL of 0.05 mg m^{-3} . Furthermore, the concentration resulting from reduction efficiencies of 99% was still 0.02 mg m^{-3} , which is almost the same as the ACGIH TLV of 0.025 mg m^{-3} .

In the case of concrete grinding work in staircases, the concentration was 4.18 mg m^{-3} and even if 99% of the RCS concentration was reduced, it would still exceed the KOEL. This means a single engineering control, such as LEV systems

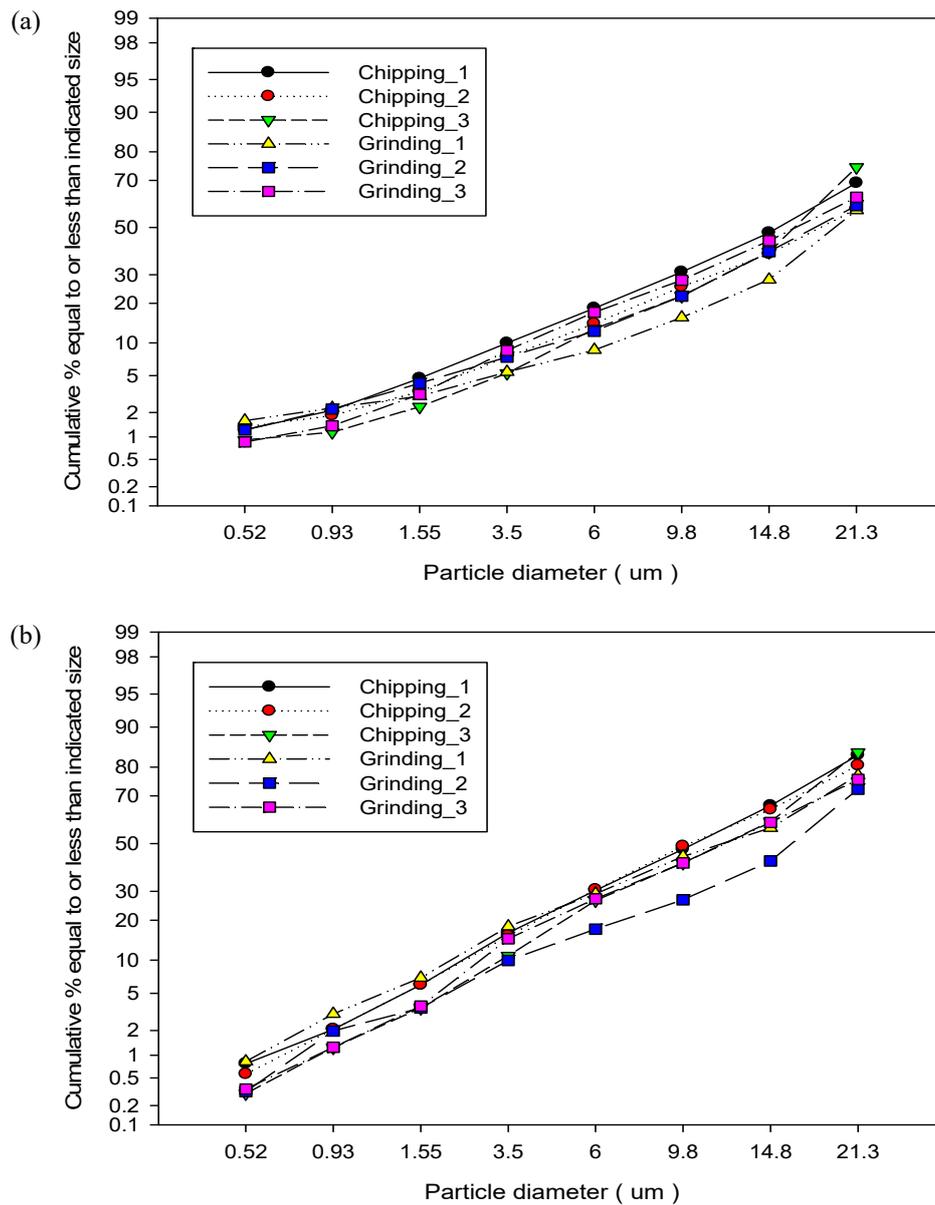


Fig. 6. Size distribution of respirable dust and respirable crystalline silica in concrete chipping and grinding: (a) respirable dust and (b) respirable crystalline silica. Table S3 presents the summary of raw data.

Table 7. Crystalline silica proportion (%) of sampled dust in each impactor stage.

Stage No.	Cut-point diameter (µm)	Crystalline silica proportion (%) of sampled dust			
		Concrete chipping		Concrete grinding	
		n	Mean ± SD	n	Mean ± SD
1	21.3	3	1.74 ± 0.69	3	1.32 ± 0.11
2	14.8	3	3.04 ± 2.20	3	1.90 ± 0.32
3	9.8	3	2.72 ± 0.59	3	2.79 ± 0.40
4	6	3	3.89 ± 1.19	3	3.75 ± 0.33
5	3.5	3	5.57 ± 2.55	3	4.81 ± 0.75
6	1.55	3	7.65 ± 3.54	3	5.51 ± 0.43
7	0.93	3	5.93 ± 5.24	3	4.90 ± 1.28
8	0.52	3	6.15 ± 2.37	3	6.74 ± 2.67
B	Backup filter	3	1.03 ± 0.21	3	1.16 ± 0.47

SD: standard deviation.

Table S4 presents the summary of raw data.

or respirators, cannot reduce RCS enough to meet acceptable exposure criteria. During concrete grinding work, multiple methods must be used to improve the work environment and reduce RCS concentrations. The following are ways to improve the work environment: using an LEV system or wet method simultaneously with high-efficiency respirators, reducing the total working time, and using full-faced air-purifying respirators. In this study, the MMAD of concrete chipping and grinding work was about 10–12 μm , which was much smaller than the MMAD of concrete cutting dust at 27.5 μm (Shepherd *et al.*, 2009). Particle size may also vary depending on the type of work tool used. For example, high-speed grinding with a diamond wheel may produce smaller particle sizes than that from cutting. However, all grinding, chipping, and cutting tasks involve mechanical actions and the MMAD of dust is larger than that of welding fumes, diesel exhaust, or smoke. Understanding the characteristics of the particle-size distribution of dust is important for reducing exposure. However, information on the particle size of silica containing dust at construction sites is very limited (Shepherd *et al.*, 2009). Further studies of dust-minimization methods based on particle-size distribution should be conducted.

CONCLUSIONS

Concrete finishing workers at apartment complex construction sites are exposed to unacceptably high concentrations of RD and RCS. Even if engineering controls, such as LEV systems, wet methods, and highly efficient respirators are applied, the RD and RCS may still exceed occupational exposure limits. To protect workers' health, dust-minimizing construction methods as well as high-efficiency respirators paired with local exhaust ventilation systems or wet methods must be employed. Further efforts to reduce the total working time and to use full-faced air-purifying respirators are required.

SUPPLEMENTARY MATERIAL

Supplementary data associated with this article can be found in the online version at <http://www.aaqr.org>.

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