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Exposure Assessment of Hazardous Substances among High-risk Construction Workers in Korea

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Exposure Assessment of Hazardous Substances among High-risk Construction Workers in Korea

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Abstracts

Exposure Assessment of Hazardous Substances among High-risk Construction Workers in Korea

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The construction industry is highly dependent upon human labor compared to other industries. Construction workers are exposed to various hazardous substances simultaneously. However, little is known about the exposure level of hazardous substances due to the characteristics of frequent workplace shifts, changes in the working environment, and the multi-level subcontractor structure.

This study was aimed at (a) identifying the exposure hazards of construction workers, (b) conducting an exposure assessment of carcinogenic substances for high-risk construction workers (excavation workers, concrete finishers, waterproof painters, welders, and asphalt road pavers), and (c) determining the variables most affecting hazardous substances concentrations and work environment improvement methods for construction workers.

Identification of the exposure hazards among construction workers by job type

The exposure hazards of 27 construction jobs were identified and summarized through a literature review and walk-through survey. Construction workers were exposed to noise, vibrations, ultraviolet rays, solar radiation, various types of dust (cement, concrete, wood, glass wool, mineral, and gypsum), and chemicals such as crystalline silica, diesel engine exhaust, asphalt fumes, asbestos, lead, chromium, epoxy/urethane, isocyanate, carbon monoxide, metal fumes, and volatile organic compounds. The most frequently exposed seven hazards were noise, vibrations, solar radiation, crystalline silica, cement/concrete dust, metal fumes, and volatile organic compounds. As for the exposure characteristics, construction workers were exposed to various hazards simultaneously, including carcinogenic substances and those with adverse reproductive effects. Among construction workers, the job types with the highest risk of exposure to carcinogens, and in which occupational cancer has been reported, were excavation workers, concrete finishers, painters, welders, and asphalt road pavers.

Exposure assessment of elemental carbon, polycyclic aromatic hydrocarbons and respirable crystalline silica among underground excavation workers

The concentration of elemental carbon (EC), organic carbon (OC), and total carbon (TC) (n = 105), polycyclic aromatic hydrocarbons (PAHs) (n = 50), respirable dust (RD) (n = 34) and respirable crystalline silica (RCS) (n=34) were evaluated inside and outside the excavator at an underground excavation worksite in four different construction sites. EC, OC, and TC were collected on a quartz filter

and analyzed using the thermal optical transmittance method. PAHs were collected on a polytetrafluoroethylene (PTFE) filter with an XAD-2 tube and analyzed using liquid chromatography with a fluorescence detector. RD and RCS were collected on a polyvinyl chloride (PVC) filter with aluminum cyclone and analyzed using Fourier-transform infrared spectroscopy. The geometric mean (GM) of respirable EC, OC, TC, total PAHs, RD, and RCS were 8.69 $\mu g/m^3$, 34.32 $\mu g/m^3$, 44.96 $\mu g/m^3$, 6.82 $\mu g/m^3$ 0.13 mg/m^3 and 0.02 mg/m^3 inside the excavator and 33.20 $\mu g/m^3$, 41.53 $\mu g/m^3$, 78.21 $\mu g/m^3$, 3.93 $\mu g/m^3$, 0.9 mg/m^3, and 0.08 mg/m^3, respectively, outside the excavator at the underground excavation worksite. The EC concentrations exceeded the recommended exposure limits as of 20 $\mu g/m^3$ accounted for about 50% of the total samples, and the GM of RCS outside the excavator exceeded 1.5 times the occupational exposure limit (OEL) of 0.05 mg/m^3. The worksites with hard rock ground, higher vehicle density, blasting work, and enclosed environments had higher worker exposure to EC than the other sites ($p < 0.05$). The most influential variables were the ground type and ventilation condition. In particular, in high-risk excavations in rocky ground and enclosed environments, more effort is needed to improve the working environment by introducing water-spraying facilities and supplying fresh air and ventilation. Furthermore, the replacement of old vehicles, regular vehicle maintenance, and the use of low sulfur oil is suggested.

Exposure assessment of RD and RCS among concrete finishing workers

The concentration of RD and RCS (n = 129) and the size distribution of the particles (n = 6) using a cascade impactor were evaluated at eight apartment complex construction sites. RD and RCS were collected on PVC filters with aluminum cyclone and analyzed

using Fourier-transform infrared spectroscopy. The GM of RCS in concrete grinding (2.06 ㎎/㎥) and concrete chipping (0.12 ㎎/㎥) exceeded 40 times and two times the OEL of 0.05 ㎎/㎥, respectively. The highest concentration of RCS in concrete grinding work was found in the staircases (4.18 ㎎/㎥), followed by the inside walls of the apartment units (2.76 ㎎/㎥), underground parking lots (1.30 ㎎/㎥), and exterior walls (0.89 ㎎/㎥). The GM of RD from concrete chipping, grinding, and plastering was 1.78 ㎎/㎥, 49.96 ㎎/㎥, and 0.37 ㎎/㎥, respectively. The mass fraction of inhalable, thoracic, and respirable crystalline silica from concrete chipping was 73.9%, 40.2%, and 17.9% and 76.0%, 46.3%, and 19.7% from concrete grinding, respectively. The highest RCS concentration was reported in concrete grinding tasks, and the smaller the space, the higher the concentration. The most influential variables were the type of task and size of the workplace. During concrete grinding work, multiple control methods must apply to improve the work environment such as local exhaust ventilation system or water-spraying facilities targeting fine-dust (less than 10 ㎛), simultaneously with the application of high-efficiency respirators.

Exposure assessment of total volatile organic compounds among construction waterproofing painters

The concentration of total volatile organic compounds (TVOCs) in waterproof painting work was monitored at eight construction sites using an organic vapor monitor (n = 88). Gas chromatography with flame ionization detection was used to identify and quantify the individual organic chemicals. The GM of the TVOCs exposure index (EI, OEL = 1) by work type was the highest when primer roller painting (1.2), followed by urethane resin spread painting (0.85), workplace area samples (0.83), mixing paint (0.53), and assisting the painter (0.35). The GM of the TVOCs EI by workplace was highest in the bathroom (1.4), followed by the swimming pool (1.37), pilot floor (0.89), ground parking lot (0.82), and rooftop (0.57). From this study, the GM of the TVOCs EI was about 78% the level of the Korea OEL (KOEL), and 38.6% of the total samples exceeded the OEL. However, when calculating the EI, according to the ACGIH-TLVs, the GM of TVOCs EI was 1.84, which was more than twice as high as when the KOEL was applied. The highest TVOCs concentration was reported in primer painting tasks in an indoor workplace. The most influential variables were the work environment (indoor vs. outdoor) and the solvent content of the paint. Indoor painting work must apply a ventilation system, and personal protective devices with an appropriate protection factor, and efforts are needed to substitute paints with fewer toxic substances.

Exposure assessment of welding fumes and metals among construction welders.

The concentration of welding fumes and metals (n = 206) was evaluated using PVC filters with gravimetric analysis and inductively coupled plasma at eight construction sites, including three apartments, two offices, two plant buildings, and one hospital. Among the different welding tasks, the welding fume exposure was the highest for general building pipefitters (4.75 mg/m^3), followed by ironworkers (3.77 mg/m^3), boilermakers (1.38 mg/m^3), metal finishing welders (0.78 mg/m^3), and chemical pipefitters (0.71 mg/m^3). Among the different welding techniques, welding fume concentrations were highest when CO_2 welding (2.08 mg/m^3), followed by shield metal arc welding (SMAW, 1.54 mg/m^3), and tungsten inert gas welding (TIG, 0.70 mg/m^3). Among the different workplaces, welding fume concentrations were highest at the underground workplace (7.75 mg/m^3) followed by the ground level workplace (2.15 ㎎/㎥). In particular, high-risk welding tasks as general building pipefitters and ironworkers, underground welding work, and CO_2 welding techniques require more attention to occupational health management, including air supply and exhaust systems, and worker training on welding fume characteristics by welding base material and welding methods.

Exposure assessment of asphalt fumes and PAHs among road pavers.

The concentration of asphalt fume (benzene soluble, n = 42) and PAHs (n = 41) was analyzed at three asphalt road pavement construction sites. Asphalt fumes were sampled using PTFE filters. PAHs were sampled using an XAD-2 tube with a glass fiber filter and analyzed using liquid chromatography with fluorescence detection. The exposure to asphalt fumes as benzene soluble aerosols was highest to road pavers (42.32 ㎍/㎥), followed by paver finisher operators (41.57 ㎍/㎥), macadam roller operators (31.9 ㎍/㎥), and tire roller operators (30.31 ㎍/㎥). The most influential variables were the asphalt temperature, the installation of hopper ventilation systems in the paver finisher, and the surrounding building conditions. The benzo(a)pyrene equivalent concentration (BaPeq) was 2.81 for paver finisher operators, 2.07 for road pavers, 0.41 for tire roller operators, and 0.25 for macadam roller operators. The BaPeq values for asphalt road paving workers was higher than that for workers in other PAHs exposure occupations even though at lower total PAHs concentrations. This study confirmed the carcinogenic exposure hazards of asphalt road paving workers.

This study identified hazardous substance exposure among construction workers. Construction workers were exposed to various

hazards simultaneously. The exposure assessment of construction workers demonstrated that excavation workers (respirable EC and RCS), concrete finishers (RD and RCS), construction painters (TVOCs), and welders (welding fume for pipefitters, boilermakers, and ironworkers) had possibilities of at least more than 5% of the exposure evaluation samples exceeded the exposure limits and their work environment was evaluated as 'poorly controlled'. Efforts are needed to eliminate hazards during design, substitute with less toxic materials and processes, remove workers from hazardous work, select appropriate equipment, reduce the time exposed to hazards, wear protective equipment and conduct regular health checks and concentration monitoring. The characteristics of the exposure in the construction industry showed large day-to-day variations due to the mobile and varied tasks. Therefore, in the future, it is necessary to apply weights for variability when evaluating the work environment monitoring results for construction workers and manage the hazard concentration within the exposure limits. These variations should be applied to the decisions regarding the appropriate sample number, homogeneous exposure groups and the estimated upper limit of concentrations for risk assessment.

This research data can be used to estimate the hazards exposure levels of construction workers when adjudicating occupational disease in health compensation insurance claims, and can contribute to improving the work environment at construction sites.

Key words: construction workers, excavation workers, concrete finishing workers, painters, welders

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Abbreviation

ACGIH	American Conference of Governmental Industrial Hygienists
AIHA	American Industrial Hygiene Association
AM	Arithmetic Mean
CI	Confidence Interval
DEE	Diesel Engine Exhaust
EC	Elemental Carbon
EI	Exposure Index
IARC	International Agency for Research on Cancer
GM	Geometric Mean
GSD	Geometric Mean
LOD	Limit of Detection
MMAD	Mass Median Aerodynamic Diameter
NIOSH	National Institute for Occupational Safety and Health
NIST	National Institute of Standards and Technology′s
NMAM	NIOSH Mannual of Analytical Methods
OEL	Occupational Exposure Limits
OC	Organuic Carbon
PAHs	Polycyclic Aromatic Hydrocarbons
PTFE	Poly Tetra Fluorene Ethylene
RCS	Respirable Crystalline Silica
RD	Respirable Dust
REL	Recommanded Exposure Limits
RR	Relative Risk
SMAW	Shielded Metal Arc Weiding
TC	Total Carbon
TEF	Toxic Equivalent Factors
TIG	Tungsten Inert Gas Welding
TLVs	Threshold Limit Values
TVOCs	Total Volatile Organic Compounds

보존용 학위논문 정오표

페이지	정정 전	정정 후

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Table S 1.

정정 전

Concrete Chipping		
Inhalable	Thoracic	Respirable
0.24	0.00	
0.16	0.02	
0.11	0.05	
0.07	0.06	
0.05	0.05	
0.03	0.03	
0.01	0.01	
0.00	0.00	
0.00	0.00	
0.674	*0.230*	
0.14	0.00	
0.14	0.02	
0.11	0.05	
0.11	0.09	
0.09	0.09	
0.09	0.09	
0.03	0.03	
0.02	0.02	
0.01	0.01	
0.739	*0.402*	

정정 후

Concrete Chipping		
Inhalable	Thoracic	Respirable
0.24	0.00	0.00
0.16	0.02	0.00
0.11	0.05	0.00
0.07	0.06	0.01
0.05	0.05	0.02
0.03	0.03	0.03
0.01	0.01	0.01
0.00	0.00	0.00
0.00	0.00	0.00
0.674	*0.230*	*0.065*
0.14	0.00	0.00
0.14	0.02	0.00
0.11	0.05	0.00
0.11	0.09	0.01
0.09	0.09	0.04
0.09	0.09	0.08
0.03	0.03	0.03
0.02	0.02	0.02
0.01	0.01	0.01
0.739	*0.402*	*0.179*

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Table 4-3.

정정 전

Ethyl benzene (ppm)
100
20
2.92(3.86)
4.31 (6.72)*
0.55 (2.16)
2.3 (3.46)
5.6 (1.58)
6.19 (3.05)*
$p<0.01$
$p<0.01$

정정 후

Ethyl benzene (ppm)	Xylene (ppm)
100	*100*
20	*100*
2.92(3.86)	*8.27(3.58)*
4.31 (6.72)*	6.74 (4.32)
0.55 (2.16)	3.33 (2.41)
2.3 (3.46)	6.19 (3.4)
5.6 (1.58)	11.06 (1.72)
6.19 (3.05)*	36.34 (2.31)
$p<0.01$	$p<0.001$
$p<0.01$	$p<0.001$

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Table 4-3.

정정 전

Bayesian decision Analysis* Exposure Rating (posterior) Decision probability (%) ($X_{0.95}$) Category**			
(1)	(2)	(3)	(4)
0	0	0	
0	0	0	
0	0	0	
0	0	0	
0	0	0	
0	0	0	
0	0.1	83.9	
0	0	22.8	
0	0	0	
0	36.5	62.9	

정정 후

Bayesian decision Analysis* Exposure Rating (posterior) Decision probability (%) ($X_{0.95}$) Category**			
(1)	(2)	(3)	(4)
0	0	0	100
0	0	0	100
0	0	0	100
0	0	0	100
0	0	0	100
0	0	0	100
0	0.1	83.9	16.1
0	0	22.8	77.2
0	0	0	100
0	36.5	62.9	0.7

보존용 학위논문 정오표

페이지	정정 전	정정 후

p. 166 Table 7-2 (d)

정정 전

Between company
n
21
84
33
9
35

정정 후

Between company	
n	GM (GSD)
21	4.75 (3.15)
84	0.71 (2.89)
33	1.38 (2.37)
9	3.77 (1.82)
35	0.78 (2.07)

p. 166 Table 7-2 (e)

정정 전

Between company
n
8
4

정정 후

Between company	
n	GM (GSD)
8	31.9 (2.66)
4	30.31 (1.79)

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정정 전

Chromium
1
1

정정 후

Chromium	Others	Total
1	*20*	*610*
	1	71
		62
		44
	1	36
1	2	36
		33
	5	24
	3	23
		22
		15
		10
	2	9
		8
		8

1. Introduction

1.1. Characteristics of construction workers

The construction industry is highly dependent upon human labor compared to other industries (Shim et al., 2012). According to a report on industrial accidents as of 2019 (MoEL, Ministry of Employment and Labor, 2020), the number of construction workers enrolled in health compensation insurance was about 2.5 million, which accounts for about 13% of all workers in South Korea, making up the third-largest proportion of domestic workers.

Recently, construction workers showed an increased risk of occupational diseases. The incidence of occupational disease per 10,000 persons in the domestic construction industry rose sharply from 1.93 in 2010 to 7.68 in 2019 (MoEL, 2020). Construction workers are likely to be exposed to carcinogenic and reproductive hazards such as respirable crystalline silica, diesel engine exhaust, asphalt fumes, asbestos, lead, metal fumes, and volatile organic compounds (Jarvholm et al., 2006). They are reported to have a higher incidence rate of cancer (Consonni et al., 2015; Lacourt et al., 2015; Calvert et al.; 2012, Arndt et al., 2004), respiratory diseases (Wang et al., 2016; Arndt et al., 2005), musculoskeletal disorders (Stocks et al., 2011), skin tumors and contact dermatitis (Stocks et al., 2010) compared to workers in general industries. A study reported that more than half of occupational cancer from asbestos, crystalline silica, polycyclic aromatic hydrocarbons, and painting work occurred in construction workers in the United Kingdom (Rushton et al., 2007).

The risk of exposure to health hazards by construction workers may vary depending upon the job type and the exposed substances. Lung cancer was reported more likely to occur in carpenters, bricklayers, cement-masons, stonemasons, welders, and waterproofing painters (Stocks et al., 2011; Calvert et al., 2012; Consonni et al., 2015), and skin tumors were higher in asphalt road pavers and painters in the construction industry (Stocks et al., 2011). While many studies have been conducted on the health symptoms and occupational diseases of construction workers, little is known about the concentration of hazards due to the job characteristics of the frequent workplace shifts, changes in the working environment, and the multi-level subcontractor structure. Also, the construction industry has focused on preventing accidents such as falls and slips, but insufficiently understands the occupational health problems of construction workers.

To protect construction workers' health, occupational health information for construction workers and construction-specific systematic management systems are necessary. The systematic health management of construction workers must identify hazardous substance exposure and high-risk tasks and prioritize targets for improving the working environment.

1.2. Construction job types and hazards

1.2.1 Classification of construction job types

The construction job types can be classified in various ways depending on the purpose. The Korean Standard Classification of Occupations (KSOC), which is used for social and economic statistical surveys in Korea, reported about 74 construction-related job types. This includes all construction-related managers, engineers, surveyors, drafters, etc., and actual construction site workers including steel structure processing workers, concrete workers, stonemasons, carpenters, plasterer, waterproofer, architectural painter, construction machine operator, etc. (Lee & Back, 2018). On the other hand, 123 construction job types are mainly used to calculate the estimated cost of construction worker wage. In this classification, the job types are divided in detail into managers, skilled technicians, and assistants according to their task proficiency (Korea Construction Association, 2019). The United States classifies occupations under the Bureau of Labor Statistics' Standard Occupational Classification (SOC). About 66 job types based on SOC were found to be related to construction (U.S. Bureau of Labor Statistics, 2019).

The Construction Workers' Retirement Credit Association classify and register about 30 integrated construction job types in the statistical yearbook (CWRCA, 2015). These job types were targeted actual construction site workers and most representative and suitable for observing the exposure hazards by construction job types. Construction occupation classification by institutions (Table 1-1) and job description and major work (Appendix Ⅰ) were summarized.

Table 1-1. Construction job type classification by institutions

Institution	Job type
The United States, Bureau of Labor Statistics' Standard Occupational Classification (SOC) (66)	Supervisors, Boilermaker, Brickmasons, Stonemasons, Carpenters, Carpet Installers, Floor Layers, Floor Sanders and Finishers, Tile and Stone Setters, Cementmasons and Concrete Finishers, Terrazzo Workers and Finishers, Construction Laborers, Paving, Surfacing, and Tamping Equipment Operators, Pile Driver Operators, Operating Engineers and Other Construction Equipment Operators, Drywall and Ceiling Tile Installers, Tapers, Electricians, Glaziers, Insulation Workers, Floor, Ceiling, and Wall, Insulation Workers, Mechanical, Painters, Construction and Maintenance, Paperhangers, Pipelayers, Plumbers, Pipefitters, and Steamfitters, Plasterers and Stucco Masons, Reinforcing Iron and Rebar Workers, Roofers, Sheet Metal Workers, Structural Iron and Steel Workers, Solar Photovoltaic Installers, Helpers, Construction and Building Inspectors, Elevator and Escalator Installers and Repairers, Fence Erectors, Hazardous Materials Removal Workers, Highway Maintenance Workers, Rail-Track Laying and Maintenance Equipment Operators, Septic Tank Servicers and Sewer Pipe Cleaners, Segmental Pavers, Construction and Related Workers, All Other, and so on
The Construction Workers' Retirement Credit Association, South Korea (30)	General Laborer, Excavating worker, Road paver worker, Concrete form worker, Architecture carpenter, Bricklayer, Plasterer, Concrete finisher, Painter, Waterproofer worker, Stonemason, Tile setter, Rebar worker, Ironworker, Concrete worker, Sash worker, Scaffolding worker, Interior worker, Plumber, Insulation worker, Demolition worker, Welder, Electrician, Construction Machine Driver, Landscaper, Construction equipment operators, Construction diver, Rock blaster, Skilled special worker, Supervisor and so on

1.2.2 Hazards by construction job types

Thiene & Spee (2008) lists possible exposure hazards by job types in the construction industry, and reported carpenters are exposed to wood dust, wood preservatives, dust, organic solvents, etc.; Pipe-layers were exposed to asbestos, dust, silica; Plasterers were exposed to cement dust, silica, organic solvents; Bricklayers were exposed to cement dust, silica; Painters were exposed to dust, epoxy, urethane, organic solvents, silica; Tile setters were exposed to cement dust, silica, epoxy, urethane, organic solvents; Concrete workers were exposed to cement dust, concrete dust; Building demolishers were exposed to asbestos, concrete dust, silica, wood dust, mineral wool, asphalt fume; Concrete finishers are exposed to concrete dust, silica; Construction equipment driver were exposed to diesel engine exhausts; Asphalt road pavers were exposed to asphalt fume, silica, solvent and diesel engine exhausts; Excavation workers were exposed to diesel engine exhausts.

Lee et al. (2011) reported that construction workers could be exposed to noise, vibration (whole body vibration, local vibration), heatwave, ultraviolet rays as physical factors; solvents, lead (containing paint), hexavalent chromium (containing wet cement), concrete dust, iron oxide dust, crystalline silica, asbestos, wood dust, welding fume, diesel engine exhaust, asphalt fume as chemical factors; the risk of cerebral cardiovascular disease; the risk of musculo-skeletal disease; biological factors such as soil bacteria and virus.

According to the Construction Solution technical data developed by the US Construction Workers' Union, noise, vibration, wood dust, and construction dust were the major hazards for carpenters; noise, construction dust, etc. for electric work; noise and vibration, construction dust, silica, etc., for heavy equipment work; noise, vibration welding fumes for blasting worker; silica, skin diseases caused by epoxy resin, whole body vibration for road pavement workers; noise, local vibration, construction dust, asbestos, etc. for interior, drywall and glass workers; noise, local vibration, construction dust, wood dust, silica, etc. for stonemasons; noise, local vibration, construction dust, silica, contact dermatitis caused by cement and epoxy resins for cement and gypsum workers; noise, local vibration, silica, contact dermatitis caused by painters, etc.; noise, local vibration, construction dust, silica, and contact dermatitis caused by cement for reinforced concrete work. Exposure hazards of 27 construction jobs (excluding supervisors and general and skilled special workers whose hazards are not specified) were summarized in Table 1-2.

CAREX (CARcinogen EXposure with support from the European Union's European Cancer Prevention Program) database provided carcinogenic substances and estimates of the number of exposed workers in the construction industry as shown in Table 1-3. CAREX Canada summarized the most prevalent carcinogen exposure estimates in the construction industry, including solar radiation, crystalline silica, wood dust, asbestos, diesel engine exhaust, wood dust, inorganic lead compounds, bitumen. benzene, chromium Ⅵ compounds, and artificial ultraviolet radiation.

Construction workers were exposed to various hazards simultaneously, including carcinogenic and reproductive substances such as respirable crystalline silica, diesel engine exhausts, asphalt fumes, asbestos, lead, metal fumes, and volatile organic compounds.

Table 1-2. Representative exposure hazards exposed of construction occupations *(Thiene & Spee, 2008; Lee et al., 2011; CWRCA, 2015, Wallk-through Survey).*

No	Job type	Exposure Hazards
1	Excavation worker	Noise, Whole body vibration, Solar radiation, Diesel engine exhaust, Cement/Concrete dust, Crystalline silica, Metal fumes, Wood dust (at sheathing wall work)
2	Road paver workers	Noise, Whole body vibration, Solar radiation, Diesel engine exhaust, Asphalt fume, Cement/Concrete dust. Volatile organic compounds,
3	Concrete form workers	Noise, Solar radiation, Cement/Concrete dust, Metal fumes, Volatile organic compounds, Wood dust
4	Architecture carpenters	Noise, Solar radiation, Wood dust, Wood preservative(copper), Glass fiber, Gypsum dust
5	Bricklayer	Noise, Solar radiation, Cement/Concrete dust, Crystalline silica.
6	Plasters	Noise, Solar radiation, Cement/Concrete dust, Crystalline silica.
7	Concrete finisher	Noise, Vibration, Solar radiation, Cement/Concrete dust, Crystalline silica.
8	Waterproof painters	Noise, Vibration(at mixing paint), Solar radiation, Cement/Concrete dust, Crystalline silica, Volatile organic compounds, Urethane, Isocyanates
9	Cauking /Tile setters	Noise, Solar radiation, Volatile organic compounds, Cement dust.
10	Stone mason	Noise, Vibration, Solar radiation, Crystalline silica, Cement dust
11	Painter	Noise, Solar radiation, Volatile organic compounds, Epoxy, Isocyanate, Metals (lead, titanium dioxide)
12	Rebar workers	Noise, Ultraviolet ray, Solar radiation, Metal fumes
13	Iron workers	Noise, Ultraviolet ray, Metal fumes,
14	Concrete workers	Noise, Whole body vibration, Solar radiation, Diesel engine exhaust, Wet cement, Concrete dust
15	Sash workers (carpenters)	Noise, Ultraviolet ray, Solar radiation, Wood dust, Metal fumes, Volatile organic compounds, Urethane, Isocyanates
16	Scaffolding worker	Noise, Ultraviolet ray, Solar radiation, Metal fumes, Cement/Concrete dust
17	Interior worker /Glaziers	Noise, Solar radiation, Volatile organic compounds, Epoxy, Isocyanate (at epoxy adhesive work), Glass fiber, Gymsum dust
18	Plumber	Noise, Solar radiation, Ultraviolet ray, Metal fumes
19	Insulation workers	Noise, Solar radiation, Volatile organic compounds, Epoxy, Isocyanate, Glass fiber dust
20	Demolition worker	Noise, Solar radiation, Asbestos, concrete dust, Wood dust, Metal fumes, Metals
21	Welder	Noise, Solar radiation, Ultraviolet ray, Metal fumes, Metals (iron oxide, zinc oxide, manganese, chromium, nickel, etc)
22	Electrician	Noise, Solar radiation, Metal fumes
23	Machine mechanic	Noise, Solar radiation, Metal fumes
24	Equipment operators	Noise, Whole body vibration, Solar radiation, Diesel engine exhaust
25	Landscaper	Noise, Solar radiation, Mineral dust, Pesticide
26	Divers	Noise, High pressure
27	Rock blaster	Noise, Vibration, Solar radiation, Cement/Concrete, Crystalline silica.

Table 1-3. Carcinogenic substances exposed construction industry_by Carex: Industry Specific Estimates by EU *(26-Mar-99)*

No	Agents	Estimates
1	Acrylamide	330
2	Strong-inorganic-acid mists containing sulfuric acid (occup.)	63,614
3	Acrylonitrile	600
4	Arsenic and arsenic compounds	14,740
5	Asbestos	573,902
6	1,3-Butadiene	1,630
7	Beryllium and beryllium compounds	490
8	Benzene	8,300
9	Carbon tetrachloride	5,680
10	Cadmium and cadmium compounds	32,113
11	Ceramic fibers	17,301
12	Cobalt and its compounds	13,631
13	Chromium VI compounds	26,181
14	Diesel engine exhaust	641,544
15	Ethylene dibromide	1,904
16	Epichlorohydrin	6,000
17	Ethylene oxide	3,000
18	Tobacco smoke (environmental)	532,746
19	Formaldehyde	60,161
20	Glasswool	622,541
21	Methylene chloride	68,146
22	Nickel compounds	5,219
23	Polycyclic aromatic hydrocarbons (excl. environmental)	146,506
24	Lead and lead compounds, inorganic	180,012
25	Pentachlorophenol	36,071
26	Tetrachloroethylene	106,182
27	Radon and its decay products	124,668
28	Silica, crystalline	2,080,435
29	Solar radiation	2,077,273
30	Styrene	31,908
31	Trichloroethylene	17,489
32	Vinyl chloride	800
33	Wood dust	1,199,888
	Total	8,701,005

1.3. High-risk group among construction workers

1.3.1 Approved occupational disease of construction workers by Korean workers' compensation

In South Korea, a total of 7,902 construction workers were reported as occupational diseases through the occupational health compensation insurance in the last 10 years (2009 ~ 2018) (Occupational Disease Statistics Database, Korea Occupational Safety and Health Agency, 2009 ~ 2018) (Table 1-3). There were 6,648 cases (84.1%) of work-related diseases, 644 cases (8.1%) of pneumoconiosis, and 610 cases (7.7%) of occupational diseases (excluding pneumoconiosis). Out of 6,648 occupational diseases, 2,891 cases (43.5%) were accidental back pain, 1,937 cases (29.1%) were body burden work, 1,014 cases (15.3%) were non-accidental back pain, 497 cases (7.5%) were cerebrovascular disease, 176 cases (2.6%) were heart diseases and 69 cases (1.0%) were mental illnesses. Out of 610 occupational diseases (excluding pneumonia), 145 cases (23.8%) were noise-induced hearing loss, 124 cases (20.3%) were bacterial and viral diseases, 77 cases (12.6%) were occupational cancer, 75 cases (12.3%) were disease from physical factors, 57 cases (9.3%) were asbestos-related disease, and 42 cases (6%) were high atmospheric pressure.

Occupational diseases (610 cases) are classified by job type as follows and summarized in Appendix Ⅱ. Occupational disease (total) occurred most in excavation workers (including rock blasting) (11.6%), general laborers (10.2%), divers (7.2%), concrete finishers (5.9%), welders (including pipefitters) (5.9%), demolition workers (5.4%), stonemasons (3.9%), painters (3.8%), insulation workers (3.6%) and so on.

- Occupational cancers were occurred most in excavation workers (including rock blasting) (14.2%), stonemasons (14.2%), concrete finishers (13.0%), welders (7.8%), insulation workers (6.5%), painters (3.9%), general laborers (3.9%), scaffolding workers (3.9%), chemical plant construction workers (3.9%).
- Noise-induced hearing losses were occurred most in excavation workers (including rock blasting) (33.1%), followed by concrete finishing workers (15.9%), general laborers (9.7%), welders (including pipefitters) (6.2%), stonemasons 4.8%), demolition workers and mechanical equipment workers (2.1%), concrete workers and rebar workers each (1.4%) and so on.
- Diseases caused by physical factors such as heat stroke were occurred most in general laborers (41.3%), followed by landscape workers (8.0%), demolition workers (6.7%), form workers (6.7%), rebar works (6.7%), panel workers (5.3%), and concrete workers (4.0%).
- Asbestos-related diseases were occurred most in insulation workers (24.6%), demolition workers (17.5%), welders (15.8%), others (8.8%), general laborers (7.0%), electricians (7.0%), and equipment operators (3.5%).
- Bacterial and viral diseases were occurred most in landscape workers (58.1%) and Diseases caused by organic compounds and solvents were occurred most in painters (35.3%), concrete workers (17.6%), and welders (11.8%) and so on.

Table 1-4. Recent 10 year's occupational disease among construction workers in South Korea

Occupational diseases	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	Total
Total	*731*	*619*	*595*	*670*	*708*	*734*	*845*	*869*	*931*	*1,200*	*7,902*
Work-Related Diseases	624	543	502	572	618	630	721	717	756	965	6,648
Liver disease		1							1		2
Cerebrovascular disease	48	51	37	41	52	42	50	45	50	81	497
Non-accidental back pain	191	210	101	102	8	61	95	42	86	118	1,014
Accidental back pain	287	174	279	314	386	301	271	325	256	298	2,891
Carpal tunnel syndrome		5	8	1		2	4	2	2	8	32
Body burden work	79	76	63	96	138	195	275	281	325	409	1,937
Heart disease	12	16	13	12	17	19	18	18	21	30	176
Others	5	8		2	4	2	6		2	1	30
Mental illness	2	2	1	4	13	8	2	4	13	20	69
Pneumoconiosis	22	35	55	63	57	52	68	85	97	110	644
Pneumoconiosis	22	35	55	63	57	52	68	85	97	110	644
Occupational illness caused by	85	41	38	35	33	52	56	67	78	125	610
Toxic Hepatitis									2		2
Physical factors (Heat wave)	1	3		3	13	6	4	9	8	28	75
Benzene	4		1							1	6
Asbestos	5	2	2		3	9	2	8	9	17	57
Bacteria, Virus	55	18	9	6		9	3	5	13	6	124
Noise	8	9	11	9	9	11	11	20	19	38	145
Mercury, Amalgam							12				12
Solvents		1							1	1	3
Organic Compound Others	4	1	1	4					4		14
High pressure	1	1	2	2	2	9	6	10	5	4	42
Others				1	1	3	5	6		4	20
Occupational Asthma					1		1				2
Occupational Skin Disease	5	4	4	4	1		2		5	1	26
Occupational Cancer	1	1	8	6	3	4	9	9	12	24	77
Vibration		1				1	1			1	4
Chromium	1										1

1.3.2 Literature review of occupational disease of consrtuction workers

The US National Library of Medicine (pubmed; https://pubmed.ncbi.nlm.nih.gov) was used to search for literatures on the health effects of construction workers. Keywords were "*Construction industry*" or "*Construction workers*" or "*Construction trade*" and "*Cancer*" or "*Respiratory disease*" or "*Asthma*" or "*COPD(Chronic Obstructive Pulmonary Disease)*" or "*Skin disease*" or "*Contact dermatitis*" or "*Allergy*". From the results of these search terms, papers were classified with epidemiological findings of the actual construction workers into 25 papers on occupational cancer, 15 papers on respiratory diseases such as asthma, and 5 papers on skin diseases (Appendix Ⅲ ~ Ⅴ).

In 25 papers on occupational cancer, lung cancer (Consonni et al., 2015; Lacourt et al., 2015; Calvert et al., 2012; Stocks et al., 2011; Arndt et al., 2004; Koskinen et al., 2002; Sun et al., 2002; Nakagawa et al., 2000; Keller et al., 1993), followed by respiratory cancer (Wang et al., 2016; Arndt et al. , 2005), skin cancer (Stocks et al., 2011; Koskinen et al., 2002; Hakanson et al., 2001), malignant mesothelioma caused by asbestos (Jarvholm et al., 2014; Dement et al., 2009), blood cancer (Hakanson et al., 2001), bladder cancer (Farzaneh et al., 2017), prostate cancer, other gastric cancer, liver cancer, pharyngeal cancer, sinus cancer (Binazzi et al., 2015) were the most reported. Respiratory crystalline silica and asbestos were the most common causes of lung cancer, and sunlight was the main cause of skin cancer. By occupation, lung cancer in carpenters (Stocks et al., 2011; Calvert et al., 2012), bricklayers (Consonni et al., 2015; Calvert et al., 2012), plasterer, and rebar workers (Sun et al., 2002), stonemasons (Calvert et al., 2012), painters (Calvert et al., 2012), pipefitters and insulation workers (Stocks et al., 2011; Arndt et al., 2004; Calvert et al., 2004; Calvert et al., 2012; Koskinen et al., 2002), welders (Calvert et al., 2012; Stocks et al., 2011; Kelle et al., 1993) and electrician (Calvert et al., 2012; Stocks et al., 2011) were reported.

Stocks et al. (2011) reported the standardized incidence rate ratios (SRRs) of occupational diseases among construction workers. The SRR of skin neoplasia was 6.3 (95% Confidence Interval (CI) 3.1 ~ 13.1) among roof waterproofing workers, 2.1 (95% CI 1.2 ~ 3.6) among painters, and 6.6 (95% CI 3.2 ~ 13.2) among general laborers. The SRR of contact dermatitis was 1.4 (95% CI 1.1 ~ 1.7) among metal workers, 1.6 (95% CI 1.1 ~ 2.3) among general laborers. The SRR of asthma was 3.8 (95% CI 2.8 ~ 5.0) among welders. The SRR of musculoskeletal diseases was 1.7 (95% CI 1.1 ~ 2.8) among welders, 6.1 (95% CI 3.8 ~ 9.6) among road construction workers, 2.5 (95% CI 1.7 ~ 3.7) among general laborers. The SRR of respiratory diseases (malignant mesothelioma, pneumoconiosis, lung cancer, etc.) was 4.5 (95% CI 3.2 ~ 6.2) among pipe installers, 2.7 (95% CI 2.4 ~ 3.2) among electricians, 2.3 (95% CI 1.9 ~ 2.7) among plumbers, 2.7 (95% CI 2.3 ~ 3.1) among carpentry and 3.3 (95% CI 2.6 ~ 4.1) among general laborers.

Jarvholm et al. (2014) studied the relative risk (RR) of malignant mesothelioma due to asbestos exposure in 189,896 Swedish construction workers. Occupations with high asbestos exposure include insulators, plumbers, pipefitters, electricians, sheet-metal workers, roofers, and floor layers. Wang et al. (2016) reported that the major cause of lung cancer in construction workers was asbestos (about 50%) and crystalline silica (about 25%). Occupations with a high risk of lung cancer include cement masons, roofers, engineers, laborers, electricians, ironworkers, carpenters, plumbers, brick masons, and sheet metal workers.

Tjoe et al. (2005) monitored 1,335 workers with high cumulative exposure to crystalline silica at construction sites and reported that more than 5% of workers exposed to crystalline silica were exposed to concentrations exceeding the exposure limits. The construction jobs with high exposure to crystalline silica were reported as concrete drilling and abrasive workers, bricklayers, building demolition workers, floor finishing workers, etc. Hakansson et al. (2001) studied the relationship between sunlight exposure and cancer incidence during outdoor work based on the data of 323,860 people who participated in the Swedish construction industry's occupational health program. The relative risk from highly exposed to sunlight adjusted with age, smoking, and magnetic field was 2.0 (95% CI 1.1 ~ 3.6) for myeloid leukemia and 1.7 (95% CI 0.9 ~ 3.2) for lymphocytic leukemia.

1.3.3 Selection of high-risk construction workers

High-risk construction job types were selected by synthesizing records of exposure to carcinogenic substances, approval of occupational disease, and occupational cancer occurrence through literature. In this study, among the job types overlapping risks, five high-risk groups were selected, considering the work frequency and populations, as follow: excavation workers, concrete finishers, painters, welders, and asphalt road pavers.

In South Korea, construction job types with an approved case for occupational cancer were stonemason, concrete finisher, excavation workers (including rock blasting workers), painters (including waterproof painters), insulation workers, plant construction workers, welders, and road pavers. Among workers exposed to carcinogens, lung cancer was reported in carpenters (Stocks et al., 2011; Calvert et al., 2012), bricklayers (Consonni et al., 2015; Calvert et al., 2012), plaster, and rebar workers (Sun et al., 2002), stonemasons (Calvert et al., 2012), painters (Calvert et al., 2012), pipefitters and insulation workers (Stocks et al., 2011; Arndt et al., 2004; Calvert et al., 2004; Calvert et al., 2012; Koskinen et al., 2002), welders (Kelle et al., 1993) and electrician (Calvert et al., 2012; Stocks et al., 2011) were reported.

· *Excavation workers*

Excavation workers are exposed to diesel engine exhaust (DEE) generated from construction heavy equipment vehicles such as excavators, and trucks and respirable crystalline silica (RCS) emitted from ground materials. DEE and RCS were classified as carcinogenic to humans (Group 1 carcinogen, IARC Monographs, 2012). The underground excavation was expected to expose high levels of hazards due to insufficient ventilation conditions, and the long duration of the work.

· *Concrete finishers*

Construction finishers are expected to expose large amounts of respirable dust and RCS by concrete grinding, chipping, and plastering work. The concrete contains RCS, and RCS was classified as a Group 1 carcinogen associated with lung cancer, silicosis, kidney failure, and lung impairment (IARC Monographs, 2012). These tasks were performed continuously until the building is finished with its exterior.

· *Construction painters*

Painters exposed to organic solvents have high incidence rates of cancers than other workers, increased prevalence of neurotoxic effects, and elevated rates of slips, trips, and falls. Painters, itself was designated as Group 1 carcinogen (IARC Monographs, 2012).

· *Construction welders*

All types of welding fumes were classified as a Group 1 carcinogen (IARC Monographs, 2018). Welding fumes contain potential cancer-causing agents, including metallic oxides, silicates, and fluorides. There are various welding task, including pipefitters, ironworkers, etc. in the construction industry,

· *Asphalt road pavers*

Asphalt fume and polycyclic aromatic hydrocarbons (PAHs) contained in asphalt concrete (ascon) are exposed to workers in the process of laying and compressing with hot ascon to a certain thickness of the floor. IARCs reported that the evidence for the association of carcinogenicity of asphalt fumes exposed in road pavement work is not yet sufficient. However, concerning ongoing research reports related to carcinogenicity, asphalt fumes have been designated as Group 2B (possible carcinogen) (IARC Monographs, 2013).

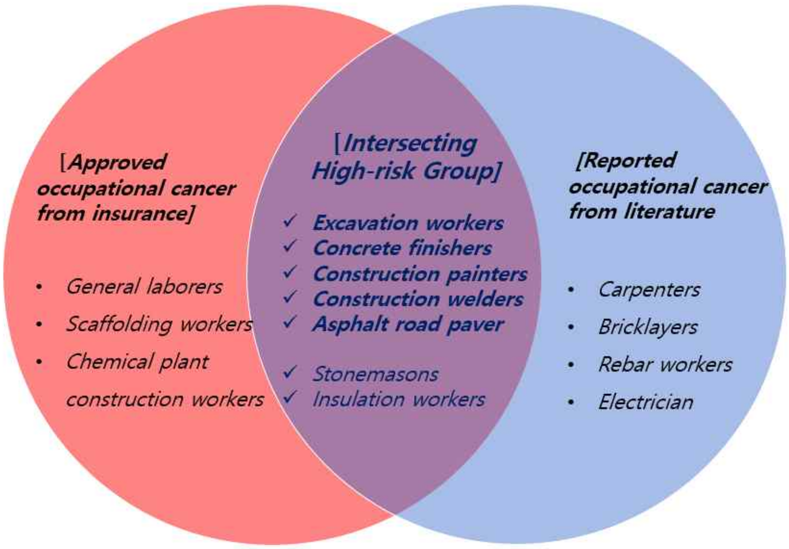

Figure 1-1. Selection of high-risk construction workers

1.4. Research scope and overview

This study was aimed at (a) identifying the exposure hazards of construction workers, (b) conducting an exposure assessment of hazardous substances for high-risk job types (underground excavation workers, concrete finishers, waterproof painters, welders, and asphalt road pavers), and (3) determining the variables most affecting on hazards concentrations and work environment improvement methods for construction workers. The job types with the highest risk of exposure to carcinogens, and in which occupational cancer has been reported, were excavation workers, concrete finishers, painters, welders, and asphalt road pavers.

This dissertation consists of 5 chapters, excluding the introduction (chapter 1) and summary (chapter 7). Chapter 2 evaluated the exposure concentration of elemental carbon (EC), organic carbon (OC), total carbon (TC), polycyclic aromatic hydrocarbons (PAHs), dust, and crystalline silica (CS) during underground excavation work for top-down construction buildings. Active local air sampling for EC, OC, and TC (n = 105), PAHs (n = 50), dust (n = 34) and CS (n = 34) was conducted from inside and outside the excavator at an underground excavation workshop in four different construction sites.

Chapter 3 evaluated the exposure concentration of respirable dust (RD) and 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 apartment complex construction sites using filters with aluminum cyclones. Local air sampling for the size distribution of the particles (n = 6) was carried out by using a mylar substrate with cascade impactors.

Chapter 4 evaluated the exposure concentration of volatile organic compounds (TVOCs) for waterproofing painters in the construction industry. Waterproof painting work was monitored at eight construction sites. Five waterproof painting work (urethane primer roller, mixing paint, urethane resin spread, painter assistant, workplace area) and five worksites (rooftop, ground floor, pilot floor, bathroom, and swimming pool) were evaluated by using passive sampling devices (Organic Vapor Monitors, OVMs). Gas Chromatograph with Flame Ionization Detector could be used for identification and quantifying individual organic chemicals. The levels of TVOCs by summing up 15 targeted substances were expressed in Exposure Index (EI) value.

Chapter 5 evaluated welding fume and metals exposure among construction welders. Activity-specific personal air sampling (n = 206) was carried out in three apartments, two offices, two plant buildings and one hospital construction sites by using a PVC (polyvinyl chloride) filter with personal air samplers. The concentration of fume and metals were showed by five different types of construction welding jobs (general building pipefitter, chemical plant pipefitter, boilermaker, ironworker, metal finishing welders).

Chapter 6 evaluated asphalt fumes (n = 42) and PAHs (n = 41) exposure among asphalt road pavers. Task-based personal air sampling was carried out in three asphalt road pavement construction using PTFE (polytetra fluoroethylene) filters for asphalt fume and an XAD-2 tube with glass fiber filters for PAHs. The concentration of fumes and PAHs were showed by four different jobs (paver finisher operator, road paver, macadam roller operator, and tire roller operator).

1.5. Objectives

The purpose of this paper is to investigate the exposure hazards of construction workers by job types and evaluate the exposure concentration of hazardous substances among high-risk construction workers. The detailed objectives of the study are as follows.

(1) To investigate the classification of job types of construction workers and identify the exposure hazards by job types from the literature and walk-through survey.

(2) To evaluate the exposure concentration of carcinogenic substances for high-risk construction workers and determine the priority target tasks to improve the working environment.
- Underground excavation workers (diesel engine exhausts (as elemental carbon), polycyclic aromatic hydrocarbons, respirable crystalline silica)
- Concrete finishing workers (respirable dust, respirable crystalline silica)
- Waterproofing painters (volatile organic compounds)
- Welder (welding fume and metals)
- Asphalt road pavers (asphalt fume and polycyclic aromatic hydrocarbons)

(3) To determining the most influential variables on concentrations and work environment improvement methods for construction workers

2. Exposure Assessment of Elemental Carbon, Polycyclic Aromatic Hydrocarbon and Respirable Crystalline silica among Underground Excavation Workers[1)]

2.1. Introduction

Crowded urban areas in Asia have experienced a recent increase in the number of construction sites that employ top-down excavation methods (Rhim et al., 2012). Top-down methods are those where the both super and sub-structures are simultaneously built, and they are useful in urban areas where there are strict environmental regulations, lack of working space, and short construction times (Jamsawang et al., 2017). Top-down construction methods include the installation of perimeter retaining walls, pre-founded columns and a horizontal structure for the support from the ground before initiating excavation work, and at this time, the floor slab is installed above the underground workplace as the excavation proceeds downwards (Rhim et al., 2012; Kang et al., 2012). Since the underground workplace is enclosed, internal ventilation therein is very poor for the excavation work. The workers engaged in excavation are exposed to diesel engine exhaust (DEE) from excavators and trucks, dust emitted from rock excavation, respirable crystalline silica (RCS), and other fumes and particulate matter. Previous studies have reported the concentration of RCS in construction sites based on typical

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occupations of tunnel construction worker (Galea et al., 2016; Radnoff et al., 2014; Bakke et al., 2002), cement mason and concrete finisher (Radnoff et al., 2014; Bakke et al., 2002; Flanagan et al., 2003; Lumens et al., 2001), and building demolition (Radnoff et al., 2014; Rappaport et al., 2003; Bello et al., 2019; Normohammadi et al, 2016). The concentration of DEE in construction sites were reported for tunnel (Galea et al., 2016; Hedmer et al., 2017; Bakke et al., 2001) and highway (Woskie et al., 2002). Although, the concentration levels and workers' exposure to contaminants in tunnel and highway construction have been reported by many researchers, its evaluation for excavation works in top-down constructions is still missing.

Underground excavation workplaces that employ the top-down construction method typically exhibit a working environment similar to mines and tunnel construction sites well known as locations with high concentrations of exposure to DEE (Pronk et al., 2009). DEE is a composite substance comprised of gaseous substances, including CO, CO_2, NO_x, and VOCs, and particulate matter, such as elemental carbon (EC), organic carbon (OC), sulfate compounds, and polycyclic aromatic hydrocarbons (PAHs) (Hedmer et al., 2017; Taxell et al., 2017). DEE is classified as a definite material causing lung cancer (Group 1) and as a suspect one causing bladder cancer (IARC, 2013). In the 1990s, EC was evaluated to be a representative, indicative substance of DEE because, in contrast with organic carbon generated from artificial or natural sources, the dominant source of EC are diesel (Pronk et al., 2009; Stewart et al., 2010). Although carbon monoxide, nitrogen monoxide, and nitrogen dioxide have been used as indicators to assess the risks of exposure to DEE in the past, there are limitations in the low specificity and sensitivity (Stewart et al., 2010; Lewine et al., 2007; Vermeulen et al, 2010; Coble et al., 2010).

Along with recent strengthening of regulations on DEE, the emission of particulate matter, including EC, from DEE has been significantly reduced. Therefore, studies using alternative indicators such as nitrogen dioxide are currently in progress. However, there are problems with doing so since nitrogen oxide can also be contained in the blasting fumes in the excavation sites from the use of blast powder (Hedmer et al., 2017). PAHs are carcinogens in DEE consisting of an aromatic hydrocarbon with more than 2 benzene rings (Miguel et al., 1998; Marr et al., 1999). PAHs, highly soluble in lipids, resulting in a higher residual tendency, bio-concentration, and easy absorption into internal organs through the lungs and skin, known to cause lung, skin, kidney, bladder cancers and reproductive mutation in DNA (Garrido et al., 2014; Boffetta et al., 1997; Bal et al., 2018). Underground excavation workers also can be exposed to RCS contained in rocks and soils in the ground while they are engaging in excavation. RCS is a Group 1 carcinogen, as defined by IARC, and has been reported to cause lung cancer, silicosis, and renal disease. There are no known treatment options other than preventive measures for diseases caused by exposure to silica (NIOSH, 2002). However, the problem is that there are no reported data on how high concentrations of crystalline silica, diesel engine exhaust and dust may be exposed to workers working in underground excavation workshops due to insufficient ventilation .

Thus the research questions of present study intends to evaluate the concentration of EC and PAHs (as representative indicators of DEE), RCS, and other respirable particulates to which workers are exposed in underground excavation sites employing top-down construction methods, and also evaluate the correlations between these hazardous substances

2.2. Materials and methods

2.2.1 Exposure group selection and task description

Four new residential complex construction sites employing top-down construction methods (Table 2-1) were selected to assess the concentration of EC, OC, TC, dust and crystalline silica in total and respirable particulates and PAHs during underground excavation work between April and May in 2017. Sites with diverse ground conditions were selected, including hard and soft rocks and soils. The construction process rate was 17 ~ 20% at the time of evaluation, and four sites were under construction on each of the 2nd and 3rd basements. The excavation work was performed by breaking rocks and transporting soil and rocks to an externally connected opening using diesel-powered engine excavators. The number of excavators used on the day of evaluation varied from 3 to 10 depending on the site situation, and the excavator's diesel engines were manufactured between 2009 and 2016, mostly Euro 5 models. At each of four construction sites, EC and PAHs were assessed for two days at three locations inside and outside the excavator. In addition, at the construction sites B and C, EC, PAHs and total dust, respirable dust and RCS were assessed outside the excavator and at construction site D, total dust, respirable dust and RCS were assessed both inside and outside the excavator for two days. Therefore, 24 EC (each total and respirable), 24 PAHs, and 6 RCS were collected inside the excavator, and 30 EC (each total and respirable), 30 PAHs, and 11 RCS were collected from the outside of the excavator. However, the results were summarized excluding some outlier and missing samples. The excavation work was carried out continuously for more than 8 hours a day, and the sample collection times ranged from 383 to 512 minutes per sample.

Table 2-1. Target monitoring workplace

Construction site	A	B	C	D
Location (City)	Busan, South Korea	Daegu, South Korea	Daegu, South Korea	Ulsan, South Korea
Sampling period	April. 2017	April. 2017	April. 2017	May. 2017
Sampling days	2	3	3	2
Ground type	Soil	Soft rock	Hard rock	Soil
Ventilation type	Half-enclosed	Enclosed	Enclosed	Enclosed
Working Ground level	Basement 3	Basement 2	Basement 2	Basement 3
Area (㎡)	7,000	3,068	8,348	3,068
Number of vehicles (Year of Manufacture)	4 (2009 ~ 2013)	5 (2010 ~ 2016)	10 (2012)	3 (2010 ~ 2015)
Area(㎡)/ No. vehicle	1,750	613.6	834.8	1022.7
Blasting work	No	No	Yes	No

2.2.2 Sampling and analysis

Elemental Carbon(EC), Organic Carbon(OC) and Total Carbon(TC) analysis

EC, OC and TC were collected on quartz-fiber filters (37-mm in diameter; SKC Inc., USA) mounted on 3-piece cassette and aluminum cyclone (SKC Inc., USA) connected to a pump (Escort Elf Pump; MSA, USA) with a flow rate of 2 L/min for total particulates and 2.5 L/min for respirable particulates. The pumps were pre- and post-calibrated using a dry calibrator (Defender 520-M; MesaLabs, USA). EC, OC and TC were analyzed using OCEC Analyzer (Model 5L; Sunset Lab. Inc., USA) in accordance with the NIOSH Manual of Analytical Methods (NMAM) of the U.S. National Institute of Occupational Safety and Health (NIOSH) #5040 (NIOSH, 2014). Three analytical samples were made from the collected quartz-fiber filter and the blank sample, introduced into the analyzer, and the concentration was calculated by multiplying the filter area (8.75 cm^2) by the average of the analyzed results for each sample. The detection limits were 0.0008 ㎍/sample of EC, 5.0527 ㎍/sample of OC, and 5.0535 ㎍/sample of TC.

Polycyclic aromatic hydrocarbons analysis

PAHs was collected on PTFE filters (Poly tetra fluoro ethylene, 37-mm in diameter, 2 ㎛pores, SKC Inc., USA) and washed XAD-2(100 ㎎/50 ㎎, ORBO 43 Supelco; Merck, Germany) connected to a pump (Escort Elf Pump; MSA, USA) with a flow rate of 2 L/min. The pumps were pre- and post-calibrated using a dry calibrator (Defender 520-M; MesaLabs, USA). Samples were wrapped in silver foil during and after sampling to prevent exposure to sunlight (heat and ultraviolet rays), refrigerated, and transported. PAHs was analyzed using a liquid chromatograph (Acquity UPLC H-Class; Waters corp., USA) -fluorescence detector (350 nm / 397 nm) in accordance with NIOSH #5506 (NIOSH, 2003a). Among the detailed compounds of PAHs, Naphtalene, Acenaphthene, Phenanthrene, Anthracene, Fluoranthene, Pyrene, Benz (a) anthracene, Chrysene, Benzo (b) fluoranthene, Benzo (k) fluoranthene, Benzo (a) pyrene, Fluorene, Acenaphthylene, Debenz (a , h) Concentrations of 16 substances such as anthracene, Benzo (ghi) perylene, and Indeno (1,2,3-C, D) pyrene were evaluated. Benzo (a) pyrene (BaP) equivalent concentration (BaP_{eq}) was estimated to find PAH carcinogenic potency relative to BaP. The detection limits and toxic equivalent factor (TEF) for each the detailed compounds of PAHs are shown in Table 2-2.

Gravimetric analysis of dust

Total and respirable dust were collected on gravimetrically analyzed PVC filters (37-mm in diameter, 5 ㎛pores; SKC Inc., USA) mounted on 3-piece cassette and aluminum cyclone (SKC Inc, USA) connected to a pump (Escort Elf Pump; MSA, USA) with a flow rate of 2 L/min for total dust and 2.5 L/min for respirable dust. The pumps were pre- and post-calibrated using a dry calibrator (Defender 520-M; MesaLabs, USA). 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 hours, 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.

Table 2-2. Detection limits of PAHs species

PAHs species	Abbreviation	Chemical Formula	MW, g/mol	Detection limits (µg /sample)	Toxic equivalent factors (TEF) (Na et al., 2004)	Occupational exposure limits (OSHA)
Naphthalene	NAP	$C_{10}H_8$	128.17	0.409	0.001	10 ppm
Acenaphthylene	ACE	$C_{12}H_8$	152.2	0.291	0.001	-
Acenaphthene	ACEN	$C_{12}H_{10}$	154.21	0.128	0.001	-
Fluorene	FLUO	$C_{13}H_{10}$	166.22	0.112	0.001	-
Phenanthrene	PHEN	$C_{14}H_{10}$	178.23	0.020	0.001	0.2 mg/m^3
Anthracene	ANTH	$C_{14}H_{10}$	178.23	0.004	0.01	0.2 mg/m^3
Fluoranthene	FLOUR	$C_{16}H_{10}$	202.26	0.026	0.001	-
Pyrene	PYR	$C_{16}H_{10}$	202.26	0.063	0.001	0.2 mg/m^3
Benz(a)anthracene	BAA	$C_{18}H_{12}$	228.29	0.006	0.1	Suspected carcinogen
Chrysene	CHR	$C_{18}H_{12}$	228.29	0.048	0.01	Animal Carcinogen
Benzo(b)fluoranthene	BBF	$C_{20}H_{12}$	252.32	0.016	0.1	Suspected carcinogen
Benzo(k)fluoranthene	BKF	$C_{20}H_{12}$	252.32	0.040	0.1	-
Benzo(a)pyrene	BAP	$C_{20}H_{12}$	252.32	0.015	1	0.2 mg/m^3, Suspected carcinogen
Dibenz(a,h)anthracene	DIB	$C_{22}H_{14}$	278.35	0.423	1	-
Benzo(ghi)perylene	GHI	$C_{22}H_{12}$	276.34	0.367	0.01	-
Indeno(1,2,3-C,D) pyrene	IND	$C_{22}H_{12}$	276.34	0.052	0.1	-

Crystalline silica analysis

After the gravimetric analysis of dust in PVC filters, crystalline silica was analyzed using Fourier-transform infrared spectroscopy (FT-IR) in accordance with the NIOSH #7602 (NIOSH, 2003b). 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 ㎎) (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 (Alpha-T; Bruker, Germany) was used to measure the sample's absorbance at 600 to 900 cm^{-1} vibrations and the absorbance at 800 cm^{-1} vibrations was used to calculate the results. The calibration curve was created from 5 to 500 ㎍using SRM2950a respirable alpha quartz from the National Institute of Standards and Technology's (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 0.009 ㎎ per sample.

2.2.3 Statistical analysis

The results were tested for normality of resources to examine the characteristics of distribution using the Shapiro-Wilk test. Evaluation groups did not follow the normal or log-normal distribution. However, the form of the data is close to the lognormal distribution. The GM mean (GM), geometric standard deviation (GSD), arithmetic mean (AM), standard deviation (SD) and median were used to explain the concentrations by construction sites. Nonparametric test and spearman correlation analysis were conducted to compare the mean exposure concentration for each construction site and to assess the relationship among EC, OC, CS and dust concentrations. 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 14.0 (Systat Software Inc., San Jose, CA, USA).

2.3. Results

2.3.1 elemental carbon, organic carbon and total carbon

Table 2-3 and Figure 2-1 shows the EC, OC, and TC concentrations from inside and outside the excavators in underground excavation sites. The GM of respirable EC, OC, and TC concentration were 8.69 ㎍/㎥, 34.32 ㎍/㎥ and 44.96 ㎍/㎥ from inside the excavator and 33.20 ㎍/㎥, 41.53 ㎍/㎥ and 78.21 ㎍/㎥ from outside the excavator in underground excavation workshop, respectively. The GM of total EC, OC, and TC concentration were 9.57 ㎍/㎥, 44.82 ㎍/㎥ and 55.94 ㎍/㎥ from inside the excavator and 32.02 ㎍/㎥, 61.29 ㎍/㎥ and 96.20 ㎍/㎥ from outside the excavator in underground excavation workshop, respectively. The EC and TC concentration from outside the excavator is significantly higher than that of inside the excavator ($p<0.01$). However, OC concentration between inside and outside the excavators is not significantly different. There was no significant difference of EC, OC, and TC concentration between total and respirable particulates.

The OC / EC ratios from inside the excavator was 4.68 (1.35 ~ 16.77) in the total particulates and 3.95 (0.83 ~ 14.95) in the respirable particulates. The OC / EC ratios from outside the excavator in the underground workshop was 1.91 (0.82 ~ 6.13) in the total particulates and 1.25 (0.62 ~ 5.28) in the respirable particulates (Table 3). The concentration of EC by the construction sites (A ~ D) were significantly different ($p < 0.0001$). However, there was no significant difference in OC concentration. The OC / EC ratio also differed according to the construction sites ($p < 0.001$) (Table 2-4, Table 2-5 and Figure 2-2).

Table 2-6 shows the respirable EC concentrations by environmental variables. By ground types, the highest concentration of EC concentration was measured in hard rock ground (27.41 ㎍/㎥), followed by the soft rock ground (9.99 ㎍/㎥), and soil ground (5.02 ㎍/㎥). The EC in enclosed work environment (11.21 ㎍/㎥) was higher than that in half-enclosed work environment (4.23 ㎍/㎥). The sites with higher vehicle density have higher respirable EC concentration (15.81 ㎍/㎥) than the sites with lower vehicle density (5.02 ㎍/㎥). However, there was a interaction between environmental variables, the analysis of covariance was used to compare means of an outcome variable between groups taking into variability of other variables. Among the variables, ground type had highest influence on EC concentration and influenced the concentration results of ventilation types, vehicle density and blasting conditions (Table 2-7).

Table 2-3. Concentration of EC, OC, TC in underground excavation worksite

(㎍/㎥)

Classification			EC	OC	TC	OC/EC(ratio)
Inside the vehicle	Total particulates	n	23*	23*	23*	23
		AM±SD	13.36±12.02	56.24±49.12	69.60±57.77	5.68±3.75
		GM(GSD)	9.57(2.325)	44.82(1.846)	55.94(1.856)	4.68(1.891)
		Median	9.12	34.93	50.77	5.21
		Range	2.09～52.22	23.78～192.81	26.47～233.66	1.35～16.77
	Respirable particulates	n	23*	23	23	23
		AM±SD	12.75±13.13	44.40±43.84	57.15±53.45	5.17±4.04
		GM(GSD)	8.69(2.425)	34.32(1.87)	44.96(1.857)	3.95(2.136)
		Median	8.44	27.64	39.86	4.44
		Range	1.57～58.43	19.11～166.90	22.90～225.33	0.83～14.95
	Kruskal-wallis_test (p value)		*0.717*	*0.009*	*0.102*	*0.339*
Outside the vehicle	Total particulates	n	29	29	29	29
		AM±SD	50.95±38.09	79.59±46.22	130.53±79.41	2.21±1.28
		GM(GSD)	32.02(3.21)	61.29(2.309)	96.20(2.516)	1.91(1.712)
		Median	53.03	91.27	159.85	1.81
		Range	3.24～132.48	9.55～171.48	13.85～303.97	0.82～6.13
	Respirable particulates	n	30	30*	30	30
		AM±SD	58.53±49.91	51.73±30.89	110.27±79.69	1.57±1.25
		GM(GSD)	33.20(3.615)	41.53(2.078)	78.21(2.556)	1.25(1.887)
		Median	53.23	52.72	115.36	1.00
		Range	3.15～191.42	8.33～123.54	12.21～314.96	0.62～5.28
	Kruskal-wallis_test (p value)		*0.785*	*0.012*	*0.172*	*$p<0.05$*
Kruskal-wallis_test b/w sampling place			*$p<0.0001$*	*$p=0.069$*	*$p<0.01$*	*$p<0.0001$*

* Log-normal distribution

※ n, Sample number; AM, Arithmetic Mean; SD, Standard deviation; GM. Geometric Mean; GSD, Geometric standard deviation

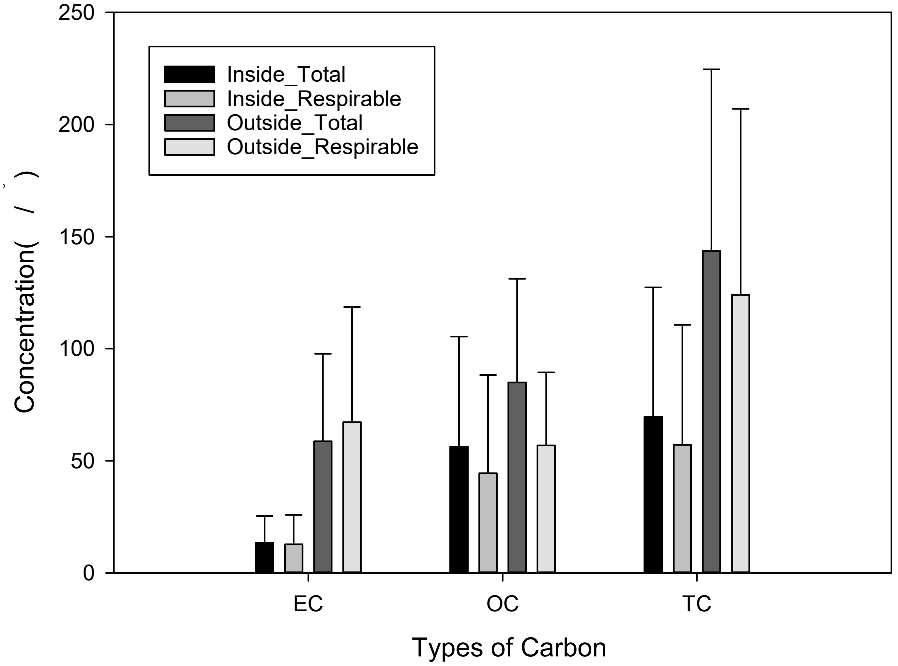


Figure 2-1. Mean concentration of EC, OC and TC, along with standard deviation (error bar), for each total and respirable particulates from inside and outside the excavator in underground excavation site

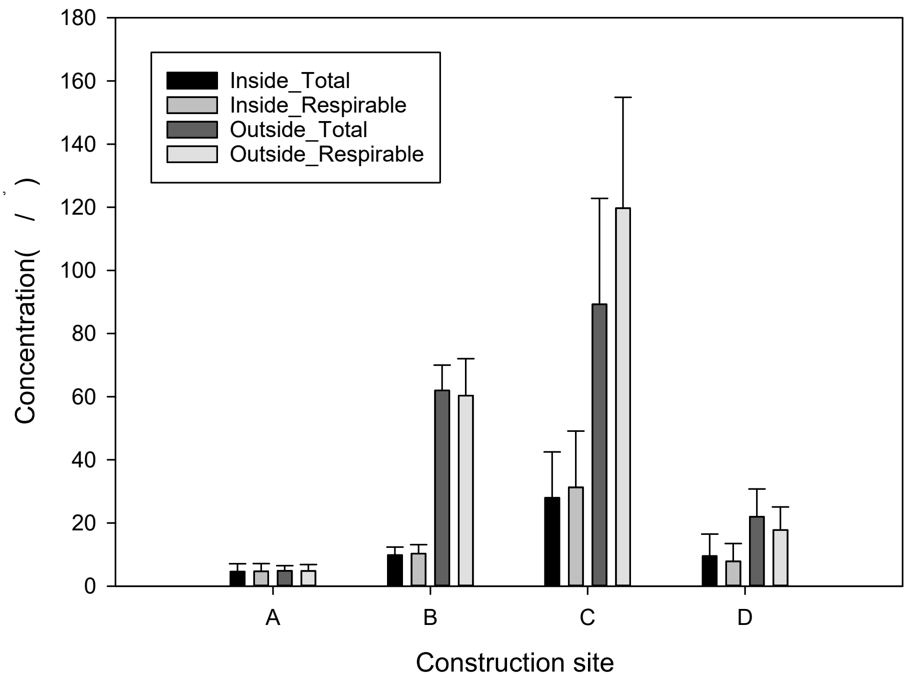


Figure 2-2. Mean concentration of EC, along with standard deviation (error bar), for each total and respirable particulates from inside and outside the excavator by target monitored construction sites.

Table 2-4. Concentration of *total* EC, OC, TC by construction site

(unit: ㎍/㎥)

Type	Construction site		EC	OC	TC	OC/EC (ratio)
Inside the vehicles	A	n	5	5	5	5
		AM±SD	4.60±2.47	28.71±4.69	33.31±6.53	7.30±2.96
		GM(GSD)	4.17(1.618)	28.41(1.174)	32.83(1.207)	6.82(1.516)
		Median	3.83	26.61	30.90	6.95
		Range	2.69～8.70	23.78～34.93	26.47～43.64	4.01～11.46
	B	n	6	6	6	6
		AM±SD	9.83±2.53	61.71±47.13	71.54±46.56	6.74±5.38
		GM(GSD)	9.58(1.281)	51.09(1.884)	62.41(1.714)	5.33(2.080)
		Median	9.04	47.59	58.75	5.32
		Range	7.26～13.72	27.77～153.05	35.02～162.18	2.49～16.77
	C	n	6	6	6	6
		AM±SD	27.99±14.52	89.31±75.99	117.3±86.88	3.04±1.80
		GM(GSD)	25.07(1.674)	66.98(2.234)	94.19(2.032)	2.67(1.714)
		Median	25.15	44.91	72.62	2.52
		Range	12.89～52.22	33.89～192.81	50.77～233.66	1.35～16.77
	D	n	6	6	6	6
		AM±SD	9.55±6.94	40.66±14.28	50.2±20.8	5.90±3.21
		GM(GSD)	7.30(2.346)	38.48(1.447)	46.44(1.555)	5.27(1.671)
		Median	7.82	41.41	50.05	5.49
		Range	2.09～19.59	24.57～54.62	26.66～74.21	2.79～11.76
Kruskal-wallis_test			*p<0.01*	*p=0.059*	*p<0.05*	*p=0.077*
Outside the vehicles	A	n	5	5	5	5
		AM±SD	4.84±1.63	16.44±4.05	21.29±4.40	3.69±1.59
		GM(GSD)	4.65(1.363)	15.95(1.343)	20.85(1.268)	3.43(1.529)
		Median	4.30	17.27	23.09	3.84
		Range	3.24～7.55	9.55～19.85	13.85～24.81	2.22～6.13
	B	n	8	8	8	8
		AM±SD	61.98±7.98	116.98±12.73	178.97±17.73	1.90±0.24
		GM(GSD)	61.53(1.138)	116.38(1.114)	178.21(1.103)	1.89(1.137)
		Median	63.37	114.88	173.48	1.84
		Range	52.53～74.32	101.04～137.85	156.03～204.07	1.53～2.20
	C	n	9	9	9	9
		AM±SD	89.30±33.51	93.84±41.0	183.13±73.04	1.10±0.25
		GM(GSD)	78.18(1.968)	83.88(1.751)	162.87(1.829)	1.07(1.236)
		Median	91.3	84.11	176.38	1.05
		Range	13.65～132.48	22.55～171.48	36.2～303.97	0.82～1.65
	D	n	7	7	7	7
		AM±SD	21.95±8.80	63.63±41.73	85.58±48.51	2.94±1.19
		GM(GSD)	19.11(1.985)	51.49(2.078)	72.02(1.983)	2.69(1.613)
		Median	24.91	42.40	62.69	3.67
		Range	4.22～31.45	16.71～127.19	20.93～158.63	1.25～4.04
Kruskal-wallis_test			*p<0.001*	*p<0.001*	*p<0.001*	*p<0.001*

Table 2-5. Concentration of *respirable* EC, OC, TC by construction site

(unit: ㎍/㎥)

Type	Construction site		EC	OC	TC	OC/EC (ratio)
Inside the vehicles	A	n	6	6	6	6
		AM±SD	4.68±2.47	25.06±4.16	29.73±4.01	6.74±4.00
		GM(GSD)	4.23(1.616)	24.77(1.182)	29.5(1.15)	5.86(1.784)
		Median	4.25	24.98	29.50	5.26
		Range	2.34～9.30	19.11～31.62	23.42～34.12	2.67～13.51
	B	n	6	6	6	6
		AM±SD	10.29±2.82	50.13±36.99	60.42±35.84	5.49±4.87
		GM(GSD)	9.99(1.293)	42.39(1.802)	54.11(1.617)	4.24(2.102)
		Median	8.70	37.55	48.38	3.98
		Range	8.23～14.43	23.4～122.99	31.84～131.21	2.03～14.95
	C	n	5	5	5	5
		AM±SD	31.28±17.83	82.5±76.81	113.78±89.64	2.50±1.93
		GM(GSD)	27.41(1.784)	54.94(2.769)	86.24(2.324)	2.00(2.086)
		Median	29.3	31.10	68.45	1.81
		Range	13.87～58.43	23.07～166.90	39.01～225.33	0.83～5.67
	D	n	6	6	6	6
		AM±SD	7.83±5.64	26.28±4.03	34.11±9.08	5.51±4.35
		GM(GSD)	5.97(2.381)	26.02(1.166)	33.08(1.315)	4.36(2.096)
		Median	6.69	25.68	34.31	4.27
		Range	1.57～16.4	21.33～31.89	22.90～45.83	1.80～13.56
Kruskal-wallis_test			*p<0.01*	*p=0.141*	*p<0.01*	*p=0.216*
Outside the vehicles	A	n	6	6	6	6
		AM±SD	4.82±1.99	13.92±3.56	18.74±4.04	3.23±1.41
		GM(GSD)	4.54(1.437)	13.51(1.321)	18.34(1.266)	2.97(1.571)
		Median	4.08	13.64	19.39	2.99
		Range	3.15～8.53	8.33～18.68	12.21～22.96	1.62～5.28
	B	n	9	9	9	9
		AM±SD	60.35±11.66	61.27±13.14	121.61±22.0	1.03±0.20
		GM(GSD)	59.34(1.217)	59.95(1.251)	119.73(1.21)	1.01(1.201)
		Median	58.88	58.73	125.95	0.99
		Range	43.15～79.01	40.27～77.22	83.42～156.23	0.77～1.45
	C	n	9	9	9	9
		AM±SD	119.7±35.13	82.08±25.05	201.78±59.64	0.68±0.06
		GM(GSD)	115.72(1.307)	78.83(1.35)	194.70(1.32)	0.68(1.090)
		Median	103.94	82.27	186.21	0.65
		Range	83.66～191.42	52.26～123.54	135.92～314.96	0.62～0.79
	D	n	6	6	6	6
		AM±SD	17.77±7.31	29.73±11.05	47.5±16.27	2.03±1.22
		GM(GSD)	15.62(1.919)	28.16(1.425)	44.84(1.476)	1.80(1.669)
		Median	19.56	24.87	46.10	1.68
		Range	4.28～25.36	18.68～46.12	22.96～67.17	1.02～4.36
Kruskal-wallis_test			*p<0.001*	*p<0.001*	*p<0.001*	*p<0.001*

Table 2-6. Concentration of respirable EC by environmental variables (unit: $\mu g/m^3$)

	n	Inside the excavator				*P value**	n	Outside the excavator				*P value**
		AM±SD	GM(GSD)	Range	95% CI			AM±SD	GM(GSD)	Range	95% CI	
Ground type												
Soil	12	6.25±4.47	5.02(2)	1.57~16.4	3.41~9.09	<0.01	12	11.29±8.47	8.42(2.27)	3.15~25.36	5.91~16.68	<0.001
Soft rock	6	10.28±2.82	9.99(1.29)	8.23~14.43	7.33~13.24		9	60.35±11.66	59.33(1.22)	43.15~79.01	51.39~69.3	
Hard rock	5	31.28±17.83	27.41(1.78)	13.87~58.43	9.14~53.42		9	119.7±35.13	115.71(1.31)	83.66~191.42	92.7~146.7	
Ventilation type												
Half-enclosed	6	4.68±2.47	4.23(1.62)	2.34~9.3	2.08~7.27	<0.05	6	4.82±1.99	4.54(1.44)	3.15~8.53	2.73~6.91	<0.001
Enclosed	17	15.59±14.21	11.21(2.37)	1.57~58.43	8.29~22.9		24	71.96±46.89	54.6(2.4)	4.28~191.42	52.16~91.76	
Area/No. excavators												
> 1,000 ㎡	12	6.25±4.47	5.02(2)	1.57~16.4	3.41~9.09	<0.05	12	11.29±8.47	8.42(2.27)	3.15~25.36	5.91~16.68	<0.001
< 1,000 ㎡	11	19.83±15.85	15.81(1.95)	8.23~58.43	9.18~30.48		18	90.02±39.71	82.86(1.51)	43.15~191.42	70.27~109.8	
Blasting												
No	18	7.6±4.37	6.32(1.94)	1.57~16.4	5.43~9.77	<0.01	21	32.32±26.69	19.44(3.21)	3.15~79.01	92.7~146.7	<0.001
Yes	5	31.28±17.83	27.41(1.78)	13.87~58.43	9.14~53.42		9	119.7±35.13	115.71(1.31)	83.66~191.42	20.17~44.47	

* Kruskal-wallis test

※ n: Sample number, AM: Arithmetic Mean, SD: Standard deviation, GM: Geometric Mean, GSD: Geometric standard deviation, CI: Confidence Interval

Table 2-7. Test of between-subjects effects (Dependent Variables: Respirable EC Concentration_inside the excavator)

Source	Type III Sum of Squares	df	Mean Square	F	p value	Partial Eta Square
Correct Model	10.441a	2	5.221	15.313	.000	.605
Intercept	2.650	1	2.650	7.774	.011	.280
Ground type	6.218	1	6.218	18.238	.000	.477
Ventilation_type	.232	1	.232	.679	.420	.033
Error	6.819	20	.341			
Total	124.819	23				
Corrected Total	17.260	22				

a. R squared = .605 (Adjusted R squared = .565)

Source	Type III Sum of Squares	df	Mean Square	F	p value	Partial Eta Square
Correct Model	10.678a	3	3.559	10.275	.000	.619
Intercept	2.813	1	2.813	8.120	.010	.299
Ground type	.023	1	.023	.068	.798	.004
Vehicles	.237	1	.237	.684	.419	.035
Ventilation_type	.467	1	.467	1.348	.260	.066
Error	6.582	19	.346			
Total	124.819	23				
Corrected Total	17.260	22				

a. R squared = .619 (Adjusted R squared = .558)

Source	Type III Sum of Squares	df	Mean Square	F	p value	Partial Eta Square
Correct Model	10.319a	2	5.159	14.865	.000	.598
Intercept	.956	1	.956	2.753	.113	.121
Ground type	1.891	1	1.891	5.449	.030	.214
Blasting_type	.109	1	.109	.314	.582	.015
Error	6.941	20	.347			
Total	124.819	23				
Corrected Total	17.260	22				

a. R squared = .535 (Adjusted R squared = .526)

Source	Type III Sum of Squares	df	Mean Square	F	p value	Partial Eta Square
Correct Model	10.678a	3	3.559	10.275	.000	.619
Intercept	.961	1	.961	2.773	.112	.127
Ground type	1.456	1	1.456	4.204	.054	.181
Vehicles	.359	1	.359	1.038	.321	.052
Blasting_type	.467	1	.467	1.348	.260	.066
Error	6.582	19	.346			

2.3.2 Polycyclic aromatic hydrocarbons

Table 2-8 and Figure 2-3 shows the concentration of total PAHs and 16 sub-compounds of PAHs from inside and outside the excavators in underground excavation sites. The concentration was calculated by summing the concentrations detected in the filter and XAD-2 tube. The GM of the total PAHs collected from inside the excavator was 6.82 $\mu g/m^3$ (1.26 ~ 23.62 $\mu g/m^3$), which was higher than that for outside the excavator in the underground workshop 3.93 $\mu g/m^3$ (1.26 ~ 15.34 $\mu g/m^3$). Naphthalene, Acenaphthylene, and Acenaphthene were dominant sub-compounds of PAHs in both inside and outside the excavators, but Pyrene is specifically high inside the excavators. Suspected and animal carcinogens (Benz (a) anthracene, Chrysene, Benzo (b) fluoranthene, Benzo (a) pyrene) were evaluated below detection limits from both in and outside the excavators, however, Benz (a) anthracene was detected inside the excavators as GM 0.004 $\mu g/m^3$ (0.004 ~ 0.037 $\mu g/m^3$). BaP_{eq} was 0.312 $\mu g/m^3$ and 0.005 $\mu g/m^3$ from inside and outside the excavator, respectively (Table 2-12). The PAHs concentration from outside the excavator was affected by environmental variables of ground type, ventilation, vehicle density and blasting ($p<0.05$) (Table 2-9).

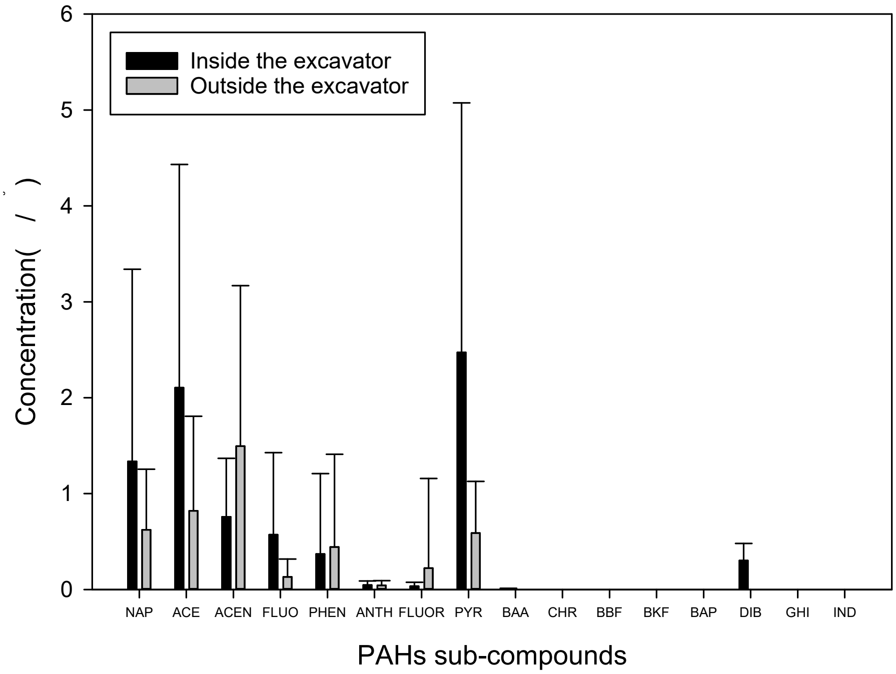


Figure 2-3. Mean concentration of PAHs sub-compounds, along with standard deviation (error bar), from inside and outside the excavator in underground excavation site

※ NAP, Naphthalene; ACE. Acenaphthylene; ACEN. Acenaphthene; FLUO, Fluorene; PHEN, Phenanthrene; ANTH, Anthracene; FLOUR, Fluoranthene; PYR, Pyrene; BAA, Benz(a)anthracene; CHR, Chrysene; BBF, Benzo(b)fluoanthene; BAP, Benzo(a)pyrene; DIB, Dibenz(a,h)anthracene; IND, Indeno(1,2,3-C,D)pyrene

Table 2-8. Comparison of PAHs concentration between inside and outside of the excavator

(unit: $\mu g/m^3$)

PAHs	n	Inside the excavator				n	Outside the excavator			
		AM±SD	GM(GSD)	Median	Range		AM±SD	GM(GSD)	Median	Range
Naphthalene	21	1.34±2.01	0.67(3.10)	0.26	0.26~8.81	29	0.62±0.63	0.42(2.29)	0.26	0.26~2.22
Acenaphthylene	21	2.10±2.33	0.98(4.05)	1.34	0.18~8.53	29	0.82±0.99	0.427(3.077)	0.18	0.18~3.44
Acenaphthene	21	0.76±0.61	0.44(3.55)	0.75	0.08~2.17	29	1.49±1.68	0.543(5.48)	1.02	0.08~5.76
Fluorene	21	0.57±0.86	0.24(3.59)	0.23	0.07~2.94	29	0.13±0.19	0.091(1.99)	0.07	0.07~0.97
Phenanthrene	21	0.37±0.84	0.11(4.44)	0.096	0.012~3.88	29	0.44±0.97	0.078(6.49)	0.063	0.012~4.14
Anthracene	21	0.047±0.042	0.032(2.9)	0.039	0.002~0.18	29	0.04±0.049	0.014(5.83)	0.018	0.002~0.14
Fluoranthene	21	0.035±0.04	0.024(2.19)	0.016	0.016~0.13	29	0.22±0.94	0.032(3.89)	0.016	0.016~5.08
Pyrene	21	2.47±2.6	1.163(4.33)	1.38	0.039~8.34	29	0.59±0.54	0.316(3.84)	0.57	0.039~2.34
Benz(a)anthracene	21	0.005±0.007	0.004(1.64)	0.004	0.004~0.037	29	> LOD	> LOD	> LOD	> LOD
Chrysene	21	> LOD	> LOD	> LOD	> LOD	29	> LOD	> LOD	> LOD	> LOD
Benzo(b)fluoranthene	21	> LOD	> LOD	> LOD	> LOD	29	> LOD	> LOD	> LOD	> LOD
Benzo(k)fluoranthene	21	> LOD	> LOD	> LOD	> LOD	29	> LOD	> LOD	> LOD	> LOD
Benzo(a)pyrene	21	> LOD	> LOD	> LOD	> LOD	29	> LOD	> LOD	> LOD	> LOD
Debenz(a,h)anthracene	21	0.30±0.18	0.28(1.36)	0.26	0.26~1.08	29	> LOD	> LOD	> LOD	> LOD
Benzo(ghi)perylene	21	> LOD	> LOD	> LOD	> LOD	29	> LOD	> LOD	> LOD	> LOD
Indeno(1,2,3-C,D)pyrene	21	> LOD	> LOD	> LOD	> LOD	29	> LOD	> LOD	> LOD	> LOD
Total PAHs		*8.34±5.24*	*6.82(1.99)*	*7.31*	*1.26~23.62*	*29*	*4.968±3.619*	*3.93(2.01)*	*3.94*	*1.26~15.34*

※ n, Sample number; AM, Arithmetic Mean; SD, Standard deviation; GM, Geometric Mean; GSD, Geometric standard deviation; LOD, Limit of Detection

Table 2-9. Concentration of PAHs by environmental variables (unit: $\mu g/m^3$)

	Inside the excavator						Outside the excavator					
	n	AM±SD	GM(GSD)	Range	95% CI	*P value**	n	AM±SD	GM(GSD)	Range	95% CI	*P value**
Ground type												
Soil	9	6.32±6.81	4.46(2.3)	1.262~23.618	1.1~11.55	<0.05	12	2.63±1.24	2.34(1.68)	1.26~4.23	1.85~3.42	<0.05
Soft rock	6	11.83±3.23	11.43(1.35)	7.133~15.795	8.45~15.22		8	7.16±5.04	5.73(2.05)	2.30~15.34	2.94~11.37	
Hard rock	6	7.86±1.70	7.69(1.27)	5.031~9.416	6.08~9.65		9	6.13±2.65	5.62(1.58)	2.52~10.93	4.1~8.17	
Ventilation type												
Half-enclosed	3	4.09±1.37	3.94(1.39)	2.906~5.587	0.68~7.49	>0.05	6	1.92±0.89	1.77(1.53)	1.22~3.44	0.98~2.85	<0.05
Enclosed	18	9.05±5.32	7.47(2.01)	1.262~23.618	6.4~11.69		23	5.76±3.65	4.85(1.83)	1.26~15.34	4.19~7.34	
Area/No. excavators												
> 1,000 ㎡	9	6.32±6.81	4.46(2.3)	1.262~23.618	1.1~11.55	<0.05	12	2.63±1.24	2.34(1.68)	1.26~4.23	1.85~3.42	<0.05
< 1,000 ㎡	12	9.85±3.22	9.37(1.39)	5.031~15.795	7.8~11.89		17	6.62±3.86	5.67(1.78)	2.30~15.34	4.63~8.6	
Blasting												
No	15	8.53±6.16	6.50(2.25)	1.262~23.618	5.11~11.94	>0.05	20	4.44±3.93	3.35(2.10)	1.26~15.34	2.6~6.28	>0.05
Yes	6	7.86±1.70	7.69(1.27)	5.031~9.416	6.08~9.65		9	6.13±2.65	5.62(1.58)	2.52~10.93	4.1~8.17	

* Kruskal-wallis test

※ n, Sample number; AM, Arithmetic Mean; SD, Standard deviation; GM, Geometric Mean; GSD, Geometric standard deviation; CI: Confidence Interval

2.3.3 Total dust, respirable dust and crystalline silica

Table 2-10 shows dust and crystalline silica concentration from inside and outside the excavators in underground excavation sites. From inside the excavator, the GM of total dust (TD), respirable dust (RD), total crystalline silica (TCS) and respirable crystalline silica (RCS) was 0.24 mg/m^3 (0.04 ~ 0.97 mg/m^3), 0.13 mg/m^3 (0.04 ~ 0.46 mg/m^3), 0.03 mg/m^3 (0.01 ~ 0.08 mg/m^3) and 0.02 mg/m^3 (0.01 ~ 0.04 mg/m^3). From outside the excavators in the underground workshop, the GM of TD, RD, TCS, and RCS was 2.5 mg/m^3 (1.13 ~ 4.56 mg/m^3), 0.90 mg/m^3 (0.46 ~ 1.62 mg/m^3), 0.17 mg/m^3 (0.07 ~ 0.29 mg/m^3) and 0.08 mg/m^3 (0.04 ~ 0.15 mg/m^3).

Table 2-10. Comparison of dust and crystalline silica concentration in total and respirable particulates in underground excavation worksites

(unit: mg/m^3)

Classification	Sampling site	Classification	Total particulate	Respirable particulate
Dust	Inside the vehicle	n	6	6
		AM±SD	0.39±0.36	0.18±0.16
		GM(GSD)	0.24(3.28)	0.13(2.57)
		Median	0.26	0.11
		Range	0.04～0.97	0.04～0.46
	Outside the vehicle	n	11	11
		AM±SD	2.74±1.16	0.97±0.38
		GM(GSD)	2.50(1.6)	0.90(1.52)
		Median	2.70	1.14
		Range	1.13～4.56	0.46～1.62
	Kruskal-wallis_test (p value)		$p<0.01$	$p<0.01$
Crystalline silica	Inside the vehicle	n	6	6
		AM±SD	0.03±0.03	0.02±0.01
		GM(GSD)	0.03(2.33)	0.02(1.86)
		Median	0.03	0.02
		Range	0.01～0.08	0.01～0.04
	Outside the vehicle	n	11	11
		AM±SD	0.02±0.09	0.09±0.04
		GM(GSD)	0.17(1.68)	0.08(1.61)
		Median	0.17	0.08
		Range	0.07～0.29	0.04～0.15
	Kruskal-wallis_test (p value)		$p<0.01$	$p<0.01$

※ n: Sample number, AM: Arithmetic Mean, SD: Standard deviation, GM: Geometric Mean, GSD: Geometric standard deviation

2.3.4 Correlation among EC, OC, TC, dust and crystalline silica concentration

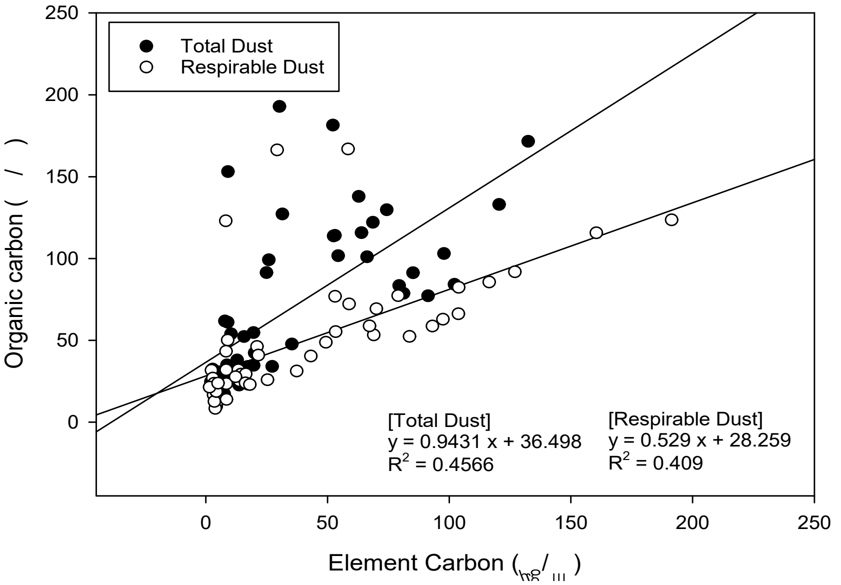
The results of the correlation analysis between EC, OC, TC, crystalline silica, and dust (Table 2-11 and Figure 2-4) showed that EC was strongly correlated with OC (r = 0.773, p <0.01) and dust concentrations (r = 0.690, p < 0.01). There was no correlation between the PAHs and EC, but a weak correlation was shown with OC (r = 0.312, p <0.01). Crystalline silica showed a strong correlation with the dust concentration (r = 0.979, p <0.01).

Table 2-11 Spearman's rank correlation of hazardous substances; EC, OC, TC, PAHs, Silica and Dust

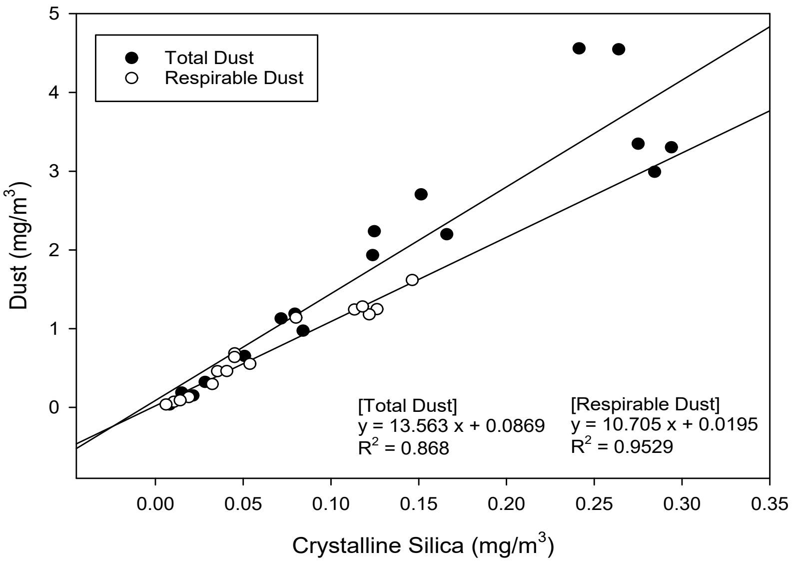
Hazards	n	EC	OC	TC	PAHs	Silica	Dust
EC	105	1	.773**	.901**	0.087	.688**	.690**
OC	105		1	.961**	.312**	.804**	.801**
TC	105			1	.258**	.731**	.723**
PAHs	98				1	0.199	0.155
Silica	33					1	.979**
Dust	33						1

※ * p<0.05, ** p<0.01

※ n, Sample number; EC, elemental carbon; OC, Organic carbon; TC, EC+OC; PAHs, Polycyclic Aromatic Hydrocarbons



(a)



(b)

Figure 2-4. Correlation between (a) elemental carbon and organic carbon, (b) crystalline silica and dust

2.4. Discussion

The evaluation of DEE (EC, OC, TC and PAHs), RCS and respiratory dust in underground excavation sites was evaluated. The EC and TC concentration from outside the excavator is significantly higher than that of inside the excavator ($p<0.01$). However, there was no significant difference between total and respirable particulates and it is estimated that approximately 80 ~ 95% particulates discharged from diesel engines have sizes below 2.5 μm (Kittleson et al., 1998). The occupational exposure limits (OEL) for EC concentrations is yet to be developed, but recently based on evidence of increased lung cancer at very low levels, the Finnish Institute of Occupational Health (FIOH) recommends the level of EC of 20 ㎍/㎥ among DEE for the underground construction workplaces including mines, and below 5 ㎍/㎥ for other industries, respectively (Vermeulen et al., 2014). Council of EU sets an exposure limit of 5 ㎍/㎥ measured in elemental carbon for all diesel engine exhaust fumes (EU, 2018). In 2019, the Dutch Expert Committee on Occupational Safety of the Health Council of the Netherlands recommended a health-based OEL for diesel engine exhaust below background levels (approximately 1 ㎍/㎥) (DECOS, 2019). However, the Mine Safety and Health Administration (MSHA) of the US Department of Labor has OEL of 160 ㎍/㎥ of concentration of TC (or 120 ㎍/㎥ of elemental carbon) to control the exposure of workers to DEE in each workplace, while the OEL of 100 ㎍/㎥ of EC has been adopted by Switzerland (Bosch et al., 2015). In 2001, the American Conference of Governmental Industrial Hygienists (ACGIH®) introduced the 'Notice of Intended Changes (NIC)' of 20 ㎍/㎥ for the concentration of EC and then canceled it later in 2003 (Bosch et al., 2015), because it exceeded the level of chronic exposure to DEE of 5 ㎍/㎥ set by the Office of Environmental Health Hazard Assessment (OEHHA), California, USA (Birch et al., 2003) by 4 times. In this study, among all EC samples evaluated in the underground excavation workplaces, 9 samples(8.5%) exceeded 100 ㎍/㎥, 34 samples(32.3%) exceeded 50 ㎍/㎥, 49 samples(46.7%) exceeded 20 ㎍/㎥, 83 samples(79.0%) exceeded 5 ㎍/㎥. Thus, pertinent control is needed over excavation equipment, such as excavators or diesel engine vehicles, employed in underground workplaces with insufficient ventilation. The concentration of hazardous elements contained in the exhaust of diesel engines varies according to the type and year of manufacture of the diesel engines, the conditions of the working environment, maintenance of the diesel engines, composition of the fuels, and presence of posttreatment device of exhaust etc. (Taxell et al., 2017; McDonald et al., 2004), thus the pertinent control and maintenance over replacement or maintenance of old vehicles, use of low sulfur fuel oils, mechanical ventilation of workplaces, and sprinkling of water etc. are needed.

Past data assessing the exposure of workers to EC in underground construction sites were not available. Regarding comparison of the data in this study with those of construction sites of tunnels, the values of GM of exposure to EC were 340 ㎍/㎥ and 100 ㎍/㎥ for workers engaged in drilling and blasting respectively in a study conducted by Bakke et al(2001). Lewne et al. (2007) evaluated the level of EC concentration of 87 ㎍/㎥ assessing in workplaces using diesel engine vehicles for tunnel construction in Stockholm. These appeared to be higher than the level of those identified in this study. Galea et al.(2016) evaluated the level of EC concentration in tunnel excavation, and the GM thereof was 18 ㎍/㎥ and highest GM in

TBM (tunnel boring machine) tunneling activities was 37 ㎍/㎥ which similar to those obtained in this study. On the contrary, the study, conducted by Hedmer et al. (2017) on the exposure of workers to EC in construction sites of railroads tunnels showed that the workers engaged in the operation of tunnel-boring machines had exposure of 2.6 ㎍/㎥of EC while the whole workplace was exposed to 11 ㎍/㎥ of EC, exhibiting a much lower level than those of the present study. The reason behind the decreased level of exposure to EC, compared to past data, was attributed to a decrease in the creation of particulate matters due to an advancement of recently developed diesel engines.

A comparison with the exposure of workers in different occupations to various levels of concentrations of EC showed similar levels of exposure to firefighters in the United States of America at 35 ㎍/㎥ (Echt et al., 1995), bus drivers in the United Kingdom at 31 ㎍/㎥ (Groves et al., 2000), and bus drivers in Estonia at 38 ㎍/㎥ (Boffetta et al., 2002). However, it the exposure was higher than that for workers of concrete pouring at 20 ㎍/㎥, workers of construction sites of express highways at 8 ㎍/㎥, workers of ordinary excavation works at 7 ㎍/㎥ (Woskie et al., 2002; Coble et al., 2010), street cleaning workers getting aboard diesel vehicles at 10.7 ㎍/㎥ (Coble et al., 2010) and 4.8 ㎍/㎥ (Lee et al., 2015), forklift drivers at 2.1 - 23.8 ㎍/㎥ (Kim et al., 2016), workers in the underground parking lots of commercial buildings at 12.2 ㎍/㎥ (Kim et al., 2013), and of workers engaged in maintenance of buses at 15.5 ㎍/㎥ (Lee et al., 2016).

Regarding the concentration of EC in different workplaces, the 'Workplace C' exhibited the highest level of concentration of EC wherein 10 excavators were running simultaneously to excavate hard rock ground. This was followed by 'Workplace B' of soft rock ground wherein 5 excavators were running simultaneously. The samples that exhibited a concentration of EC over 100 ㎍/㎥ were all detected at 'Workplace C'. 'Workplace A' and 'Workplace D' with grounds having relatively higher portion of soils had a lower concentration of EC. Therefore, EC concentration varied according to the type of ground, the number of excavators running simultaneously, and the states of ventilation, etc. Among the variables, ground type had highest influence on EC concentration and influenced the concentration results of ventilation types, vehicle density and blasting work

The GM of OC/EC ratio in this study from inside the excavator was 3.95 in the respirable particulate, whereas that outside the excavator appeared at 1.25, suggesting the concentration of organic carbon (OC) appeared relatively higher inside the vehicle. In general, it is known that OC/EC ratio ranges from 2 ~ 3 for the urban area (Na et al., 2004). The OC/EC ratios observed in this study shows that inside the excavator has average higher and underground workshop has average lower than general urban atmosphere.

The concentration of total PAHs was higher inside the excavator than outside the excavator in the underground workplace, contrary to results of the concentrations of EC, RCS and particulates. It is presumed that there was internal pollutants since undetected PAHs sub-compounds from outside the excavator were detected from inside the excavators. However, it was beyond the limitations of this study. The concentration of total PAHs inside the excavator and in the underground workplace were 6.82 ㎍/㎥ and 3.93 ㎍/㎥, respectively, which was lower than the 32.62 ㎍/㎥ of road pavers in asphalt pavement sites (Park et al., 2018), 17.5 ㎍/㎥ of the paint manufacturing industry (Lee., 2005), 526.55 ㎍/㎥ of the shop of steel pipe coating (Lee., 2005), 10.631 ㎍/㎥of tar production process in the manufacturing industry of chemical products (Lee., 2004), and higher than 1.884 ㎍/㎥ in vehicle inspection factory in Korea (Im et al., 2004) and 0.056 ㎍/㎥ (vehicles of gasoline engine), 0.112 ㎍/㎥ (bus), and 0.199 ㎍/㎥ (vehicles of diesel engine) in vehicle inspection factory in Beijing, China (Li et al., 2013). However, the BaP_{eq} from inside the excavator was similar with that of paint manufacturing and carbon black industry (Lee et al., 2005; Tsai et al., 2001) and the BaP_{eq} from outside the excavator was similar with that in vehicle inspection factory (Li et al., 2013) and that of traffic policeman in roadsides (Hu et al., 2007). The total PAHs of this study was higher than that of highway toll station (Zhao et al., 2016), but the BaP_{eq} was lower. Table 2-12 shows the PAHs concentrations reported in earlier studies Bakke et al.(2001) evaluated the exposure of 25 workers engaged in drilling, blasting, and concrete work inside of tunnels to PAHs, and reported that all samples appeared to be less than the detection limit (< 0.2 ㎍/㎥). Benz(a)anthracene, Chrysene, Benzo(b)fluoranthene, and Benzo(a)pyrene are among 16 sub-compounds of PAHs known to be carcinogens, and they were found to be lower than the detection limit. Thereby, the risk of carcinogenesis was estimated to be low. While the low-molecular PAHs of 3 benzene rings or below are mainly generated from diesel engines, the high molecular PAHs, such as Benzo [a]pyrene and Dibenz[a,h]anthracene etc., are known to be generated from gasoline engines (Miguel et al., 1998; Marr et al., 1999). In contrast, regarding the level of dust concentration in the underground excavation workplaces (employing top-down approach), the GM of total and respirable dust from outside the excavator was 2.50 ㎎/㎥ and 0.90 ㎎/㎥ respectively. which were approximately 10 times higher than the concentration inside the excavator. The GM of 0.08 ㎎/㎥ of the concentration of RCS among respirable particulates exceeded OEL by approximately 1.5 times, suggesting the presence of risk to catch silicosis or lung cancer. No past assessment on the exposure to RCS concentration in the underground excavation works in construction sites was available. Regard a comparison of construction sites, the exposure of workers drilling, blasting, and conducting concrete works to RCS, as shown in the study conducted by Bakke et al. (2001) was reported with GM of 0.025 ㎎/㎥ and 0.033 ㎎/㎥, while Galea et al. (2016) reported the exposure of workers engaged in the concrete lining in a tunnel construction site to RCS (in concentration) with GM of 0.03 ㎎/㎥, and approximately 1/10 of all samples exceeded the level of concentration of RCS of 0.1 ㎎/㎥ in their study. These were similar to the results obtained from the present study. The concentration of TD and RD from outside the excavators was 10 times higher than that of inside the excavators. Brodny and Tutak (Brodny et al., 2018) reported the level of harmful dust on fully powered longwall coal mines and the research results showed that type of activities and working location had a significant effect on the level of dust exposed. The concentration of RD from outside the excavators was similar with laborer(2.46 ㎎/㎥) and bricklayer(2.13 ㎎/㎥) (Rappaport et al., 2003) and much lower than that of painter blaster(13.50 ㎎/㎥) (Rappaport et al., 2003), tuck pointer(15.40 ㎎/㎥) (Flanagan et al., 2003), recess miller(5.08 ㎎/㎥) and demolition workers(23.67 ㎎/㎥) (Lumens et al., 2001). Dust showed a strong correlation with the crystalline silica concentration.

Table 2-12. The PAHs concentration reported in earlier studies

Occupational Environments	Process	ΣPAHs (AM. ㎍/㎥)	BaP (㎍/㎥)	BaPeq (㎍/㎥)	Country	Reference
Construction industry Underground Excavation	Inside the vehicle	8.34	-	0.312	S.Korea	This study
	Outside the vehicle	4.97	-	0.005	S.Korea	
Asphalt road pavement	Paver finisher operator	42.3	0.359	2.813	S.Korea	Park et al., 2018
	Road paver	32.618	0.267	2.071		
	Macadam roller operator	7.675	0.104	0.248		
	Tire roller operator	10.792	-	0.410		
Paint Manufacturing	-	17.48	0.3	0.394	S.Korea	Lee, 2004
Steel pipe coating	-	526.54	0.7	1.986		
Tar Manufacturing	Personal	17.09	0.003	0.034	S.Korea	Lee, 2005
	Environmental	12.97	0.11	0.46		
Vehicle Inspection factory	-	1.884	0.007	0.017	S.Korea	Im et al., 2004
Waste Incineration	-	6.066	0.015	0.039		
Vehicle Inspection factory	Bus line	0.112	0.00135	0.00438	China, Beijing	Li et al., 2013
	Gasoline line	0.0561	0.00131	0.00334		
	Diesel line	0.199	0.00434	0.0124		
Carbon black industry	Packaging	1.953	0.341	0.566	Taiwan	Tsai et al., 2001
	Palletizing	1.449	0.285	0.314		
Traffic policeman	Road intersections	0.867	0.0262	0.0824	China, Tianjin	Hu et al, 2007
	Roadsides	0.0466	0.0015	0.0057		
	On Campus	0.0195	0.0007	0.0024		
Highway toll station	-	0.330	0.0216	0.0413	China, Tianjin	Zhao et al., 2016

2.5. Conclusions

This study is the first hazards exposure assessment of underground excavation worker in top-down construction buildings. The EC and RCS concentrations from outside the excavator is significantly higher than those of inside the excavator ($p<0.01$). EC concentrations during underground excavation work exceeded recommended exposure limits as 20 ㎍/㎥, accounted for about 50% of the total sample, and the level of concentration of RCS exceeded the 1.5 times of occupational exposure limit, 0.05 ㎎/㎥. The worksites with hard rock ground, higher vehicle density, blasting work and enclosed environments had higher exposure to EC than other sites ($p<0.05$) and the most influential variables were ground type and ventilation condition. Efforts are needed to introduce water-spraying facilities at rock ground excavation worksites and supply of fresh air and ventilation. Furthermore, replacement of old vehicles, regular vehicles maintenance, use of low sulfur oil were suggested.

3. Exposure Assessment of Respirable dust and Crystalline Silica among Concrete Finishing Workers[2)]

3.1. 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 (Sauvé et al., 2013; Flanagan et al., 2003; 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 (Sauvé et al., 2013; Flanagan et al., 2003; Oude et al., 2014; Rappaport et al., 2003; Tjoe et al, 2003). Many studies have reported that the concentration of RCS exceeded OEL in various construction jobs including concrete workers such as recess millers, tuck pointers, and bricklayers; demolition workers; laborers; operating engineers; and even construction cleaners (Rappaport et al., 2003; Tjoe et al, 2003; Lumens and Spee., 2001).

Crystalline silica is defined as a Group 1 carcinogen by the

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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 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 sites 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 chapter was to evaluate the exposure levels and size distribution of RCS among concrete finishers at the large-scale apartment complex construction sites

3.2. Materials and methods

3.2.1 Exposure group selection and task description

Eight new apartment complex construction sites (Table 3-1) 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 (Figure 3-1(a)) refers to using a hammer drill to cut off uneven concrete walls after removing the molding used to cure the concrete. Concrete grinding (Figure 3-1(b)) is the use of a grinder to level a concrete surface after removing the molding. The grinder used for this study included a four-inch industrial diamond wheel. Plastering work (Figure 3-1(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 three 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, 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 3-1) were collected to represent each concrete finishing work hazard concentration. The samples were collected during work hours and several samples (up to four samples/day) were collected from a single worker when processes changed during the day or measured concentration was high. The sample collection times ranged from 55 ~ 523 minutes per sample. To identify the size distribution of crystalline silica, six cascade impactor samples were collected at construction site G during work hours for two consecutive days and the sample collection times ranged from 210 ~ 912 minutes per sample.

Table 3-1. Target monitoring of workplace and number of sample

No	Site	No, of house holds	Sampl ing 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


(a)


(b)


(c)

Figure 3-1. Concrete chipping(a), grinding(b) and plastering(c) work

3.2.2 Sampling and analysis

Sampling

Respirable dust was collected on gravimetrically analyzed PVC filters (37 mm in diameter, 5 ㎛pores, SKC Inc., USA) mounted on aluminum cyclone (SKC) connected to a pump (MSA Escort Elf Pump, USA) with a flow rate of 2.5 L/min. The pumps were pre- and post-calibrated using a bubble calibrator (standard flow 20 ccs to 6 L/min) (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 hours, 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 ㎎) (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 (JASCO FT/IR-4600, Japan) was used to measure the sample's absorbance at 600 ~ 900 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 ㎍using SRM1878a respirable alpha quartz from the National Institute of Standards and Technology's (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 ㎍ 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, Anderson Sampler Inc., USA) composed of an eight-stage impact plate was used. Mylar Substrate (TE-290-My, 34 mm, Mylar 6-slot, 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 NP, 1989). In the last stage, a PVC (5-㎛pore size) filter was installed to even the flow of air. The flow was set at about 2 L/min 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 (Anderson Sampler Inc., 1982). The corrected weight of dust was used to calculate the mass fraction (%) of each stage (Table S 1, 3-2). 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).

3.2.3 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 workplaces. ANOVA and Pearson correlation analysis with log-transformed data were conducted to compare the mean exposure concentration for each job type and each workplace 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, workplaces, and sampling (work) time. The types of jobs and workplaces 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).

3.3. Results

3.3.1 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 concentration 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 ㎎/㎥ (0.10 ~ 17.62 ㎎/㎥), which exceeded the Korean Occupational Exposure Limit (KOEL, 0.05 ㎎/㎥ which is the same as the U.S. Occupational Safety and Health Administration's permissible exposure limits) by 41.2 times, based on an eight-hour work shift (Figure 3-2). In addition, the GM of RCS exposure from concrete grinding work was more than 80 times the ACGIH TLV (threshold limit value) for crystalline silica (0.025 ㎎/㎥). All samples exceeded OEL of 0.05 ㎎/㎥. The GM of RCS exposure from concrete chipping was 0.123 ㎎/㎥ (0.005 ~ 3.06 ㎎/㎥) and 75% of the samples (27/36) exceeded 0.05 ㎎/㎥. The GM of RCS exposure from plastering work was 0.003 ㎎/㎥ (ND ~ 0.027 ㎎/㎥) and no sample exceeded 0.05 ㎎/㎥. The GM of RD exposure from concrete grinding was 49.96 ㎎/㎥ (4.26 ~ 367.58 ㎎/㎥), which exceeded the ACGIH's TLV for general dust (respirable, particulate not otherwise regulated) of 3 ㎎/㎥ by about 16.6 times. The exposure to concrete chipping workers was 1.78 ㎎/㎥ (0.19 ~ 62.72 ㎎/㎥) and 0.37 ㎎/㎥ (0.086 ~ 1.07 ㎎/㎥) for plastering work. All samples exceeded 3 ㎎/㎥ in concrete grinding and 27.7% (10/36) of the concrete chipping worker samples exceeded 3 ㎎/㎥. The job types with highest GSD were 4.13, 3.23, 2.86 for RCS concentration and 3.26, 2.84, and 2.87 for RD concentration in chipping, grinding and plastering.

Table 3-2. Respirable dust and Respirable Crystalline Silica concentrations by type of concrete finishing works. (㎎/㎥)

Job	n	Respirable Dust					Respirable Crystalline Silica				
		Normality Test (Shapiro-Wilk)	AM ±SD	GM (GSD)	Range	Exc Fra %	Normality Test (Shapiro-Wilk)	AM ±SD	GM (GSD)	Range	Exc Fra %
Concrete Chipping	36	Log-normal (p=0.088)	4.55 ±11.07	1.78 (3.26)	0.19 ~62.72	27.7% (10/36)	Log-normal (p=0.905)	0.32 ±0.60	0.12 (4.13)	0.005 ~3.06	75% (27/36)
Concrete Grinding	58	Log-normal (p=0.183)	78.6 ±76.56	49.96 (2.84)	4.26 ~ 367.58	100% (58/58)	Log-normal (p=0.095)	3.54 ±3.67	2.06 (3.23)	0.10 ~17.62	100% (58/58)
Plastering	35	- (p<0.001)	0.42 ±0.22	0.37 (1.86)	0.086 ~1.07	0 % (0 /35)	Log-normal (p=0.894)	0.006 ±0.006	0.003 (2.86)	ND ~0.027	0 % (0 /35)
ANOVA analysis			p < 0.001					p < 0.001			

※ n, Number of samples; 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 ㎎/㎥)and respirable crystalline silica (0.05 ㎎/㎥); ND, Not Detected

3.3.2 RD and RCS in concrete finishing by type of workplace and worksites

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 workplace showed that the GM was highest in a staircase at 4.18 ㎎/㎥ (range, 0.49 ~ 17.62 ㎎/㎥) (Figure 3-3 and Table 3-3). The GM was 2.76 ㎎/㎥ (range, 0.45 ~ 7.75 ㎎/㎥) inside the apartment units, 1.30 ㎎/㎥ (range, 0.10 ~ 5.16 ㎎/㎥) in the underground parking lots, and 0.89 ㎎/㎥ (range, 0.14 ~ 1.85 ㎎/㎥) at the exterior walls. Evaluation of the concentrations of respirable dust at each concrete grinding workplace showed that the GM was 95.54 ㎎/㎥ (range, 10.45 ~ 367.58 ㎎/㎥) in the staircases, 38.73 ㎎/㎥ (range, 5.94 ~ 131.2 ㎎/㎥) in the apartment units, 39.98 ㎎/㎥ (range, 4.26 ~ 250.99 ㎎/㎥) in the underground parking lots, and 27.22 ㎎/㎥ (range, 19.40 ~ 37.61 ㎎/㎥) at the exterior walls.

By workplace (Table 3-3 (a)), the GSD of concrete chipping were 2.38 ~ 7.85 for RCS concentration and 2.39 ~ 5.03 for RD concentration. The GSD of concrete grinding were 2.71 ~ 3.4 for RCS concentration and 1.34 ~ 2.82, for RD concentration. The GSD of plastering were 1.18 ~ 2.66 for RCS concentration and 1.07 ~ 3.59 for RD concentration.

By worksites (Table 3-3 (b)), The GSD of concrete chipping were 1.61 ~ 10.2 for RCS concentration and 2.23 ~ 11.58 for RD concentration. The GSD of concrete grinding were 1.09 ~ 2.97 for RCS concentration and 1.12 ~ 2.84 for RD concentration. The GSD of plastering were 1.66 ~ 2.77 for RCS concentration and 1.33 ~ 2.44 for RD concentration. The concrete chipping shows higher GSD than grinding and plastering.

Table 3-3(a). Respirable dust and silica concentrations of concrete finishing work by construction workplace. (㎎/㎥)

Job	Workplace	n	Respirable Dust				Respirable Crystalline Silica			
			AM ±SD	GM (GSD)	Range	Exc Fra %	AM ±SD	GM (GSD)	Range	Exc Fra %
Concrete chipping	Exterior wall	7	2.35 ±2.70	1.59 (2.39)	0.61 ~8.30	14.3% (1/7)	0.2 ±0.216	0.139 (2.38)	0.04 ~0.68	85.7% (6/7)
	Inside Apartment units	11	7.94 ±18.30	2.03 (5.03)	0.24 ~62.72	36.4% (4/11)	0.49 ±0.89	0.11 (7.85)	0.005 ~3.06	72.7% (8/11)
	Staircase	1	1.014	1.014	1.014	-	0.048	0.048	0.048	-
	Underground Parking lot	17	3.46 ±6.63	1.77 (2.86)	0.19 ~28.79	29.4% (5/17)	0.28 ±0.48	0.13 (3.26)	0.017 ~2.07	76.4% (13/17)
ANOVA analysis			P > 0.05 (p = 0.940)				P > 0.05 (p = 0.912)			
Concrete grinding	Exterior wall	4	28.11 ±8.12	27.22 (1.34)	19.40 ~37.61	100% (4/4)	1.27 ±0.77	0.89 (3.4)	0.14 ~1.85	100% (4/4)
	Inside Apartment units	11	56.0 ±40.39	38.73 (2.82)	5.94 ~131.2	100% (11/11)	3.85 ±2.55	2.76 (2.71)	0.45 ~7.75	100% (11/11)
	Staircase	17	135.17 ±103.51	95.54 (2.61)	10.45 ~367.58	100% (17/17)	6.18 ±5.22	4.18 (2.71)	0.49 ~17.62	100% (17/17)
	Underground Parking lot	26	58.95 ±51.35	39.98 (2.76)	4.26 ~250.99	100% (26/26)	2.03 ±1.62	1.30 (3.02)	0.10 ~5.16	100% (26/26)
ANOVA analysis			P < 0.05 (p = 0.017)				P < 0.05 (p = 0.003)			
plastering	Exterior wall	2	0.60 ±0.04	0.59 (1.07)	0.57 ~0.62	-	0.025 ±0.004	0.024 (1.18)	0.022 ~0.027	-
	Inside Apartment units	19	0.52 ±0.21	0.39 (3.59)	0.002 ~1.074	-	0.003 ±0.003	0.002 (2.66)	ND ~0.009	-
	Underground Parking lot	14	0.27 ±0.15	0.22 (1.87)	0.086 ~0.54	-	0.006 ±0.005	0.005 (2.22)	0.001 ~0.021	-
ANOVA analysis			P > 0.05 (p = 0.229)				P < 0.05 (p = 0.002)			

※ n, No. of sample; AM, Arithmetic Mean; SD, Standard Deviation; GM, Geometric Mean; GSD, Geometric Standard Deviation; Exceeding fraction (%), Exceeding fraction of the occupational exposure limit of respirable dust (3 ㎎/㎥) and respirable crystalline silica (0.05㎎/㎥)

Table 3-3(b). Respirable dust and silica concentrations of concrete finishing work by construction worksites. (㎎/㎥)

Job	Worksite	No. of sample	Respirable Dust				Respirable Crystalline Silica			
			AM ±SD	GM (GSD)	Range	Exc Fra %	AM ±SD	GM (GSD)	Range	Exc Fra %
Concrete chipping	A	3	1.81 ±1.66	1.38 (2.42)	0.69 ~3.72	33.3% (1/3)	0.069 ±0.035	0.064 (1.61)	0.048 ~0.11	33.3% (1/3)
	B	3	3.83 ±3.86	2.56 (3.15)	0.82 ~8.19	33.3% (1/3)	0.42 ±0.42	0.28 (3.11)	0.092 ~0.89	100% (3/3)
	D	8	4.49 ±9.84	1.19 (4.58)	0.24 ~28.79	12.5% (1/8)	0.28 ±0.72	0.037 (6.37)	0.005 ~2.07	37.5% (3/8)
	E	10	2.64± 2.27	1.98 (2.23)	0.61 ~8.30	30% (3/10)	0.24 ±0.20	0.17 (2.46)	0.039 ~0.68	90% (9/10)
	G	10	1.98 ±1.29	1.49 (2.52)	0.19 ~3.68	30% (3/10)	0.22 ±0.15	0.16 (2.74)	0.017 ~0.48	90% (9/10)
	H	2	32.34 ±42.96	11.1 (11.58)	1.96 ~62.72	50% (1/2)	1.59 ±2.09	0.59 (10.20)	0.115 ~3.06	100% (2/2)
ANOVA analysis			P > 0.05 (p = 0.268)				P < 0.05 (p = 0.041)			
Concrete grinding	A	18	137.81 ±107.34	92.21 (2.84)	10.45 ~367.58	100% (18/18)	5.73 ±5.31	3.56 (2.97)	0.49 ~17.62	100% (18/18)
	B	6	87.1 ±44.18	69.77 (2.45)	12.01 ~131.2	100% (6/6)	3.92 ±2.45	2.88 (2.74)	0.57 ~6.55	100% (6/6)
	C	2	74.62 ±25.05	72.49 (1.41)	56.90 ~92.33	100% (2/2)	3.56 ±1.05	3.48 (1.35)	2.82 ~4.3	100% (2/2)
	D	8	56.13 ±26.49	50.61 (1.65)	24.13 ~105.00	100% (8/8)	1.48 ±1.45	0.98 (2.66)	0.31 ~4.18	100% (8/8)
	E	2	6.77 ±1.17	6.72 (1.19)	5.94 ~7.6	100% (2/2)	0.48 ±0.042	0.47 (1.09)	0.45 ~0.51	100% (2/2)
	F	8	36.65 ±18.23	29.84 (2.33)	4.26 ~65.27	100% (8/8)	1.77 ±0.70	1.62 (1.65)	0.57 ~2.68	100% (8/8)
	G	2	5.10 ±0.58	5.09 (1.12)	4.69 ~5.51	100% (2/2)	0.12 ±0.028	0.12 (1.26)	0.10 ~0.14	100% (2/2)
	H	12	53.38 ±30.47	45.28 (1.86)	18.49 ~108.16	100% (12/12)	3.69 ±2.14	2.76 (2.83)	0.14 ~7.75	100% (12/12)
ANOVA analysis			P < 0.05 (p = 0.000)				P < 0.05 (p = 0.000)			
plastering	C	3	0.4 ±0.34	0.094 (2.44)	0.002 ~0.62	-	0.019 ±0.011	0.016 (2.13)	0.007 ~0.027	-
	D	7	0.15 ±0.066	0.13 (1.51)	0.086 ~0.28	-	0.006 ±0.004	0.004 (2.18)	0.002 ~0.013	-
	E	3	0.46 ±0.18	0.43 (1.57)	0.26 ~0.62	-	0.006 ±0.003	0.005 (1.66)	0.003 ~0.008	-
	F	16	0.56 ±0.17	0.54 (1.34)	0.27 ~1.074	-	0.003 ±0.003	0.002 (2.77)	0~0.01	-
	G	6	0.37 ±0.10	0.36 (1.33)	0.23 ~0.54	-	0.006 ±0.007	0.004 (2.42)	0.001 ~0.021	-

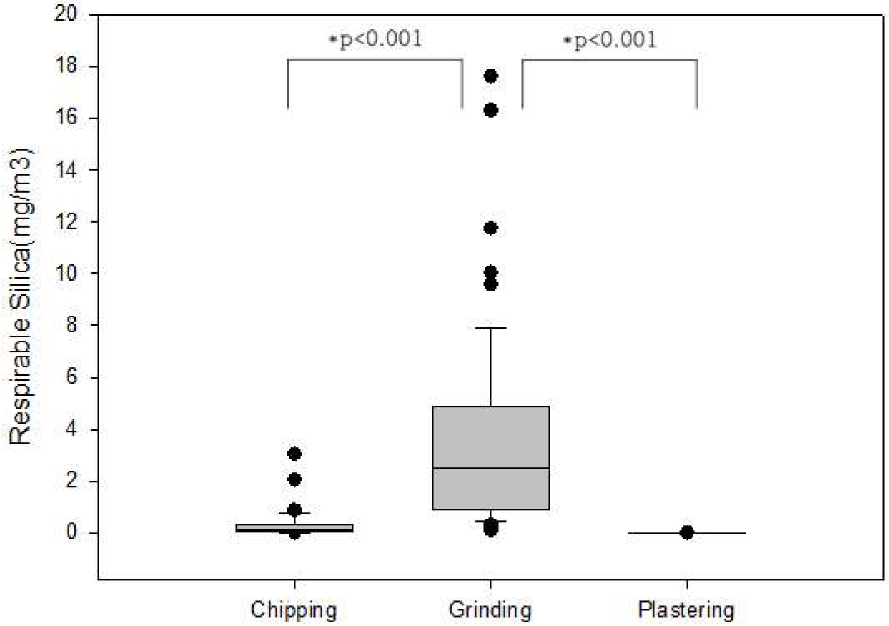


Figure 3-2. Respirable crystalline silica exposure concentration by concrete finishing job.

※ 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, grinding vs plastering)

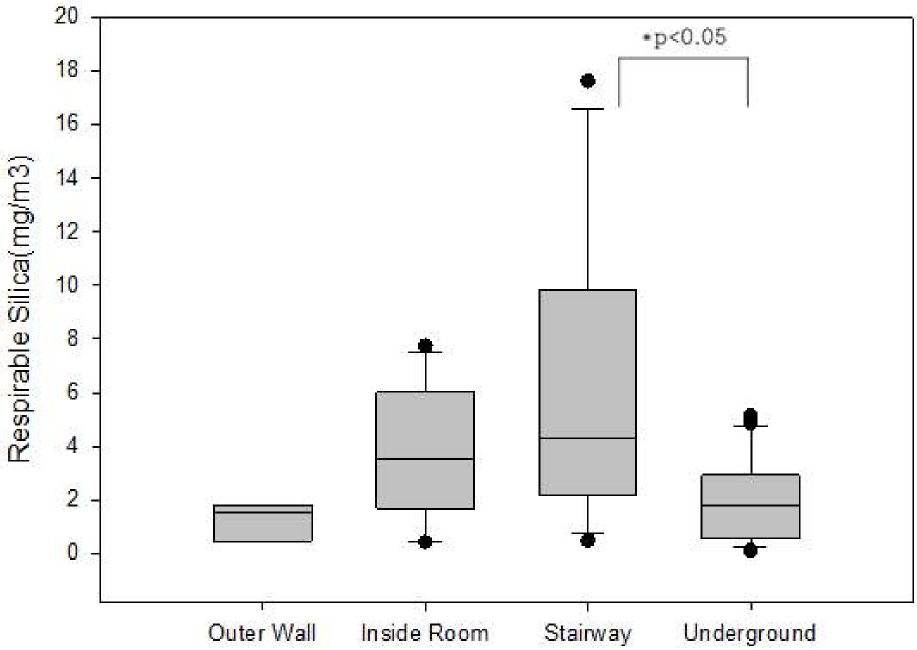


Figure 3-3. Respirable crystalline silica exposure concentration of concrete grinding work by workplace.

※ 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, grinding vs plastering)

3.3.3 Correlation between dust and silica concentration by job type

Evaluation of the proportion of crystalline silica in the dust from each job type showed that the crystalline silica content was higher for concrete chipping work. The crystalline silica content was 6.92 % in chipping work, 4.12 % in grinding, and 0.94 % in plastering work (Table 3-5). The correlation coefficients between RCS and RD were 0.970 ($p < 0.01$) for chipping work, 0.793 ($p < 0.01$) for grinding, and 0.100 ($p = 0.568$) for plastering work (Figure 3-4 and 3-5).

Table 3-4. 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±SD	GM(GSD)	
Concrete Chipping	36	8.00±3.80	6.92(1.81)	0.970 *
Concrete Grinding	58	5.00±2.72	4.12(2.03)	0.793 *
Plastering	35	1.70±1.71	0.94(3.52)	0.100
Total	129	4.94±3.68	3.19(3.19)	0.864 *

*$p < 0.01$

※ AM, Arithmetic Mean; SD, Standard Deviation; GM, Geometric Mean; GSD, Geometric Standard Deviation

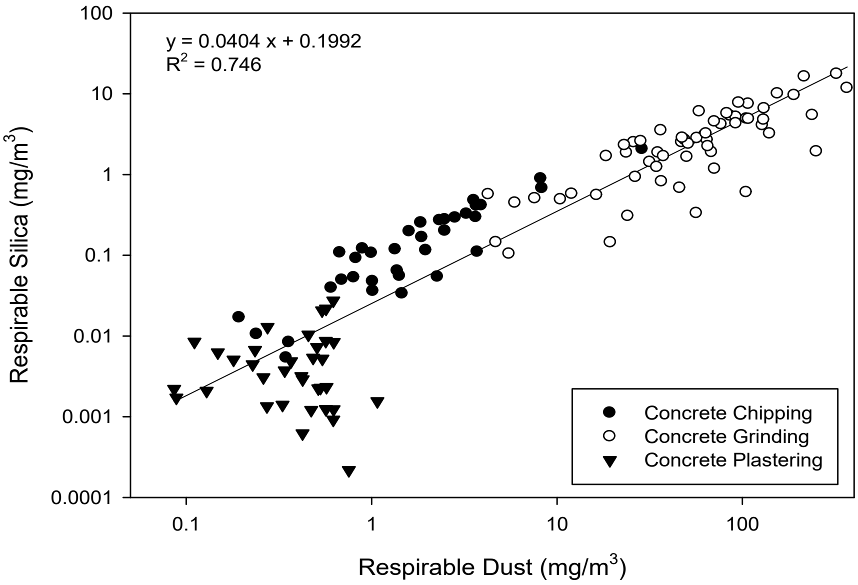


Figure 3-4. Respirable dust and silica concentration by concrete finishing job type

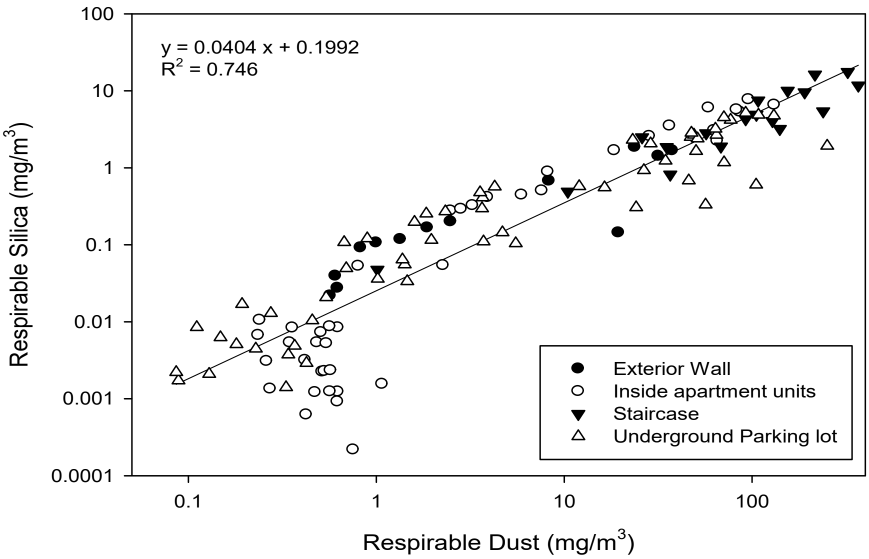


Figure 3-5. Respirable dust and silica concentration by workplace type

3.3.4 Size distribution of particles from concrete finishing

The mass fraction of inhalable, thoracic, and respirable dust from concrete chipping in the construction sites was 67.4%, 23.0%, and 6.5%, respectively, and was 68.7%, 26.6%, and 7.9%, from concrete grinding, respectively. The mass fraction of inhalable, thoracic, and respirable crystalline silica from concrete chipping was 73.9%, 40.2%, and 17.9% and 76.0%, 46.3%, and 19.7% from concrete grinding, respectively (Table 3-6). A cumulative graph of the weights of dust collected from each stage was plotted from the stage with the smallest particle size (stage, 0.52 ㎛or smaller) in order to draw a trend line and determine the median diameter of the mass using an effective diameter limit corresponding to 50% cumulative probability. The result indicated that the median mass diameter of dust was 11.51 ㎛ for concrete chipping and 11.05 ㎛ for concrete grinding (Figure 3-6(a) & Table S3). The results indicated that the median mass diameter of respirable crystalline silica was 9.59 ㎛ for concrete chipping and 8.86 ㎛ for concrete grinding (Figure 3-6(b) & Table S3). Considering the proportion of crystalline silica in the dust from each stage, the crystalline silica content was higher in the dust with smaller particle sizes. The content was particularly high in stage 6 (range, 1.55 ~ 3.5 ㎛) and stage 8 (range, 0.52 ~ 0.93㎛) (Table 3-7).

Table 3-5. 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

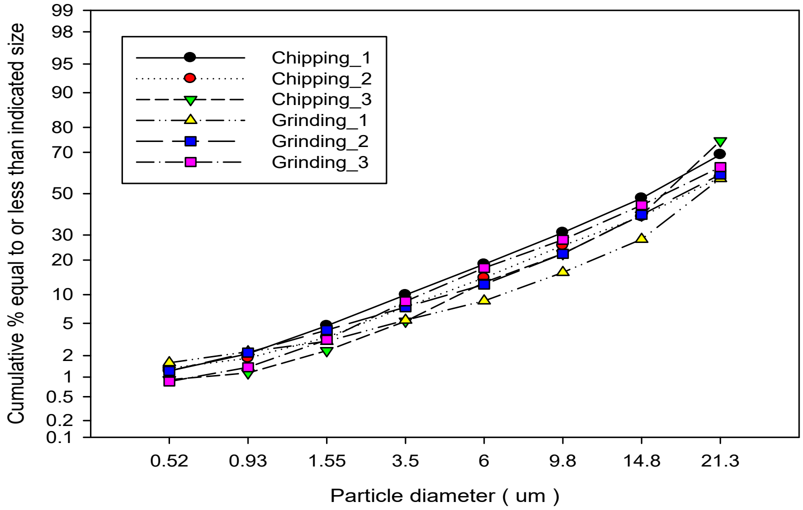
※ Table S 1 and 2 present the summary of raw data

Table 3-6. Crystalline silica proportion (%) of sampled dust in each impactor stage

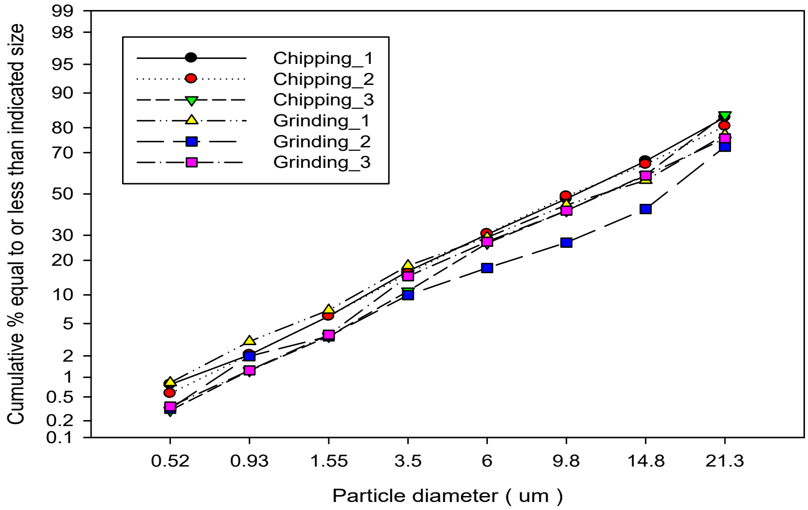
Stage No.	Cut-Point Diameter (㎛)	Crystalline silica proportion (%) of sampled dust			
		Concrete Chipping		Concrete Grinding	
		n	Mean±SD	n	Mean±SD
1	21.3	3	1.74±0.69	3	1.32±0.11
2	14.8	3	3.04±2.20	3	1.90±0.32
3	9.8	3	2.72±0.59	3	2.79±0.40
4	6	3	3.89±1.19	3	3.75±0.33
5	3.5	3	5.57±2.55	3	4.81±0.75
6	1.55	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 S 4 present the summary of raw data



(a) Respirable Dust



(b) Respirable Crystalline Silica

Figure 3-6. Size distribution of respirable dust and respirable crystalline silica in concrete chipping and grinding (a) Respirable Dust, (b) Respirable Crystalline Silica

※ Table S3 present the summary of raw data

3.4. Discussion

The RD and RCS concentrations present during concrete chipping, grinding, and plastering work was evaluated at eight apartment complex construction sites. All RCS samples from concrete grinding work and 75% of the RCS samples from chipping work exceeded the KOEL (0.05 mg/m^3). The 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 workplace, 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. The GSD were 4.13, 3.23, 2.86 of RCS concentration and 3.26, 2.84, and 2.87 of RD concentration for chipping, grinding and plastering. The high GSD indicate that there are probabilities exist to show much higher concentration of unmeasured construction sites.

Previous studies have reported (Table S 5) GM concentrations of 0.7 mg/m^3 and 0.42 mg/m^3 for a recess miller (Tjoe et al., 2003; Lumens and Spee, 2001), 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 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 the size of the each apartment unit is very narrow. Specifically, in concrete grinding work, where a concrete face is polished by more than 10,000 rotations per minute using an industrial diamond wheel, very 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., 2010; Meeker et al., 2009; Akbar-Khanzadeh et al., 2007), the water spray method (Meeker et al., 2009; Beamer et al., 2005; 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 water spray 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 workplace.

Although the LEV systems and the water spray method showed significant reductions in concentrations and workers wore half-mask respirators, some workers were still overexposed to RCS because the maximum reduction rate of the concentration of RCS was about 99% as existing scheme (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 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 water spray method simultaneously with high-efficiency respirators, reducing the total work time, and using air-purifying full-faced respirators. In this study, the MMAD of concrete chipping and grinding work was about 10 to 12μm, which was much smaller than the MMAD of concrete cutting dust at 27.5μm (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

3.5. Conclusions

Concrete finishing workers at apartment complex construction sites are exposed to unacceptably high concentrations of RD and RCS. Most influential variables were type of task and size of workplace. The highest RCS concentration was reported at concrete grinding tasks and the smaller the space, the higher the concentration. The RCS concentration of concrete grinding at the staircase was so high that the concentration could not be reduced with single engineering improvement method. The concrete grinding work must apply multiple control methods to improve the work environment such as local exhaust ventilation system or water spray facilities targeting on fine-dust (less than 10 ㎛), simultaneously with high-efficiency respirators must be applied. Further efforts to reduce total work time and use air-purifying full-faced respirators should also be suggested.

Supplementary Material

Table S 1. Inhalable, thoracic and respirable fractions in concrete chipping work

Hazards	Impactor Stage No.	Effective ness	Concrete Chipping						Total Stage Conc./Total Impactor Conc.	Average Inhalable Fraction	Average Thoracic Fraction	Average Respirable Fraction	Concrete Chipping	
			Sampled Concentration(Conc.) (㎎/m3)			Corrected Concentration(Conc.) (㎎/m3)							Inhalable	Thoracic
			#1	#2	#3	#1	#2	#3						
Dust	1	0.52	10.48	3.66	11.53	20.15	7.03	22.17	0.42	0.567	0.008	0.000	0.24	0.00
	2	0.61	8.42	2.07	6.87	13.81	3.40	11.26	0.24	0.670	0.102	0.000	0.16	0.02
	3	0.78	4.12	2.27	7.53	5.29	2.92	9.65	0.15	0.740	0.337	0.005	0.11	0.05
	4	0.89	2.52	1.43	5.53	2.84	1.61	6.22	0.09	0.812	0.670	0.065	0.07	0.06
	5	0.95	0.86	0.70	4.80	0.90	0.74	5.05	0.06	0.876	0.861	0.361	0.05	0.05
	6	0.96	0.44	0.42	2.89	0.45	0.44	3.01	0.03	0.930	0.930	0.819	0.03	0.03
	7	0.97	0.00	0.20	0.76	0.00	0.20	0.79	0.01	0.964	0.964	0.963	0.01	0.01
	8	0.99	0.00	0.02	0.00	0.00	0.02	0.00	0.00	0.979	0.979	0.979	0.00	0.00
	F	1.00	0.09	0.07	0.21	0.09	0.07	0.21	0.00	0.992	0.992	0.992	0.00	0.00
	Sum					43.52	16.44	58.36	1.00				*0.674*	*0.230*
Silica	1	0.52	0.15	0.10	0.16	0.28	0.19	0.32	0.24	0.567	0.008	0.000	0.14	0.00
	2	0.61	0.15	0.12	0.13	0.25	0.20	0.22	0.21	0.670	0.102	0.000	0.14	0.02
	3	0.78	0.12	0.08	0.18	0.15	0.11	0.23	0.15	0.740	0.337	0.005	0.11	0.05
	4	0.89	0.17	0.06	0.17	0.19	0.06	0.19	0.14	0.812	0.670	0.065	0.11	0.09
	5	0.95	0.13	0.05	0.15	0.14	0.05	0.16	0.11	0.876	0.861	0.361	0.09	0.09
	6	0.96	0.13	0.04	0.14	0.14	0.04	0.15	0.10	0.930	0.930	0.819	0.09	0.09
	7	0.97	0.05	0.01	0.03	0.05	0.01	0.03	0.03	0.964	0.964	0.963	0.03	0.03
	8	0.99	0.03	0.01	0.01	0.03	0.01	0.01	0.02	0.979	0.979	0.979	0.02	0.02
	F	1.00	0.01	0.00	0.00	0.01	0.00	0.00	0.01	0.992	0.992	0.992	0.01	0.01
	Sum					1.24	0.68	1.31	1.00				*0.739*	*0.402*

Table S 2. Inhalable, thoracic and respirable fractions in concrete grinding work

Hazards	Impactor Stage No.	Effectiveness	Concrete Grinding						Total Stage Conc./Total Impactor Conc.	Average Inhalable Fraction	Average Thoracic Fraction	Average Respirable Fraction	Concrete Grinding		
			Sampled Concentration(Conc.) (㎎/㎥)			Corrected Concentration(Conc.) (㎎/㎥)							Inhalable	Thoracic	Respirable
			#1	#2	#3	#1	#2	#3							
Dust	1	0.52	11.37	25.81	5.93	21.86	49.63	11.40	0.37	0.567	0.008	0.000	0.21	0.00	0.00
	2	0.61	9.05	13.68	9.97	14.83	22.43	16.34	0.24	0.670	0.102	0.000	0.16	0.02	0.00
	3	0.78	9.01	11.36	6.01	11.55	14.56	7.70	0.15	0.740	0.337	0.005	0.11	0.05	0.00
	4	0.89	7.70	11.20	3.68	8.65	12.59	4.14	0.11	0.812	0.670	0.065	0.09	0.08	0.01
	5	0.95	5.44	6.74	3.22	5.73	7.09	3.39	0.07	0.876	0.861	0.361	0.06	0.06	0.03
	6	0.96	3.17	3.61	1.11	3.30	3.76	1.16	0.04	0.930	0.930	0.819	0.03	0.03	0.03
	7	0.97	1.26	0.65	0.32	1.30	0.67	0.33	0.01	0.964	0.964	0.963	0.01	0.01	0.01
	8	0.99	0.06	0.00	0.00	0.06	0.00	0.00	0.00	0.979	0.979	0.979	0.00	0.00	0.00
	F	1.00	0.32	0.40	0.21	0.32	0.40	0.21	0.00	0.992	0.992	0.992	0.00	0.00	0.00
	Sum					67.60	111.13	44.66	1.00				*0.687*	*0.266*	*0.079*
Silica	1	0.52	0.17	0.32	0.08	0.32	0.62	0.16	0.18	0.567	0.008	0.000	0.10	0.00	0.00
	2	0.61	0.20	0.31	0.16	0.33	0.50	0.26	0.18	0.670	0.102	0.000	0.12	0.02	0.00
	3	0.78	0.28	0.39	0.15	0.36	0.50	0.19	0.17	0.740	0.337	0.005	0.13	0.06	0.00
	4	0.89	0.30	0.51	0.14	0.33	0.58	0.16	0.17	0.812	0.670	0.065	0.14	0.12	0.01
	5	0.95	0.26	0.45	0.15	0.27	0.48	0.16	0.15	0.876	0.861	0.361	0.13	0.13	0.05
	6	0.96	0.19	0.29	0.07	0.20	0.30	0.08	0.09	0.930	0.930	0.819	0.09	0.09	0.08
	7	0.97	0.07	0.12	0.02	0.08	0.13	0.02	0.04	0.964	0.964	0.963	0.04	0.04	0.04
	8	0.99	0.02	0.05	0.01	0.02	0.05	0.01	0.01	0.979	0.979	0.979	0.01	0.01	0.01
	F	1.00	0.02	0.02	0.00	0.02	0.02	0.00	0.01	0.992	0.992	0.992	0.01	0.01	0.01
	Sum					1.94	3.18	1.04	1.00				*0.760*	*0.463*	*0.197*

Table S 3. Cumulative probability graph formula and mass median diameter of respirable dust

Job	Sample	Cumulative probability graph formula		Mass median diameter (Cumulative probability 50% diameter)	
		Respirable dust	Respirable Crystalline Silica	Respirable dust	Respirable Crystalline Silica
Concrete Chipping	#1	y = 4.4197x - 3.9448	y = 4.6447x + 7.2745	12.206 ㎛	9.198 ㎛
	#2	y = 4.4784x - 1.4026	y = 4.7037x + 0.0399	11.477 ㎛	10.621 ㎛
	#3	y = 4.5591x + 0.0392	y = 4.7634x + 5.097	10.958 ㎛	9.426 ㎛
Concrete Grinding	#4	y = 4.633x + 1.528	y = 4.8639x + 7.6436	10.462 ㎛	8.708 ㎛
	#5	y = 4.4416x - 0.9722	y = 4.8058x + 7.5818	11.476 ㎛	8.826 ㎛
	#6	y = 4.8272x - 2.5319	y = 4.972x + 4.1777	10.882 ㎛	9.216 ㎛

Table S 4. Crystalline silica proportion (%) of sampled dust in each impactor stage

Stage No.	Cut-Point Diameter (㎛)	Crystalline silica proportion (%) of sampled dust							
		Concrete Chipping				Concrete Grinding			
		Sample # 1	Sample # 2	Sample # 3	Mean ±SD	Sample # 1	Sample # 2	Sample # 3	Mean ±SD
1	21.3	1.302	2.531	1.383	1.74±0.69	1.39	1.19	1.38	1.32±0.11
2	14.8	1.683	5.580	1.866	3.04±2.20	2.12	2.05	1.53	1.90±0.32
3	9.8	2.473	3.389	2.292	2.72±0.59	2.92	3.10	2.33	2.79±0.40
4	6	5.206	3.600	2.870	3.89±1.19	3.58	4.13	3.54	3.75±0.33
5	3.5	8.127	5.557	3.022	5.57±2.55	4.27	5.68	4.50	4.81±0.75
6	1.55	11.390	7.213	4.340	7.65±3.54	5.11	5.957	5.46	5.51±0.43
7	0.93	11.974	2.951	2.858	5.93±5.24	4.04	6.38	4.29	4.90±1.28
8	0.52	8.390	6.385	3.672	6.15±2.37	3.74	7.65	8.84	6.74±2.67
B	Backup Filter	1.260	0.978	0.861	1.03±0.21	1.66	1.08	0.73	1.16±0.47

※SD, Standard Deviation

Table S 5. Previous studies reported on the RCS concentration in construction sites

Construction Type	Job(Task)	n	RCS Concentration(㎎/㎥)			Country	Reference
			AM±SD	GM (GSD)	Range		
Apartment complex	Concrete chipping	36	0.32±0.60	0.12(4.13)	0.005 ~ 3.06	S.Korea	This study
	Concrete grinding	58	3.54±3.67	2.06(3.23)	0.10 ~ 17.62		
	Plastering	35	0.006±0.006	0.003(2.86)	N.D. ~ 0.027		
General Building	Recess millers	53	1.43	0.7 (3.3)	N.D. ~ 6.9	Netherlands	Lumens M et al., 2001
	Inner wall constructiors	36	0.06	0.04 (2.6)	N.D. ~ 0.2		
	Demolition workers	82	2.88	1.1 (4.0)	N.D. ~ 35.9		
General Building	Recess Miller/concrete work	14	1.09	0.42 (5.0)	0.036 ~ 4.7	Netherlands (1999)	Tjoe E et al., 2003
	Tuck pointers	10	0.56	0.35 (2.8)	0.089 ~ 1.6		
	Demolition workers	21	0.25	0.14 (2.7)	0.038 ~ 1.3		
	Innerwall construction	4	0.043	0.036 (2.0)	0.016 ~ 0.084		
	Construction site cleaner	12	0.032	0.017 (3.6)	0.0016 ~ 0.0097		
Office Building	clean up	11	-	0.03 (2.79)	-	United States (2000-2001)	Flanagan ME et al., 2003
	Hans demolition	14	-	0.10 (2.60)	-		
	Concrete cutting	15	-	0.07 (2.78)	-		
	Concrete mixing	9	-	0.02 (1.99)	-		
	Tuck point grinding	12	-	0.22 (1.94)	-		
	Surface grinding	23	-	0.63 (4.12)	-		
	Sack and patch concrete	13	-	0.03 (2.22)	-		
	Concrete floor sanding	9	-	0.07 (2.62)	-		

Table S 5. Previous studies reported on the RCS concentration in construction sites_*continued*

Construction Type	Job(Task)	n	RCS Concentration(㎎/㎥)			Country	Reference
			AM(±SD)	GM (GSD)	Range		
Various construction site	Painter and painter blaster	14	Median 1.28	-	0.260 ~ 26.2	United States (1992-2000)	Rappaport SM et al., 2003
	Bricklayer	11	Median 0.32	-	0.007 ~ 14.2		
	Operating engineer	46	Median 0.075	-	0.007 ~ 0.8		
	Laborer and drill runner	80	Median 0.35	-	0.007 ~ 5.9		
Highway construction (asphalt pavement milling)	Operator_A site	11	0.0071	0.0062(2.02)	Max 0.013	United States	Hammond D et al., 2016
	Ground worker_A site	11	0.0066	0.0061(1.72)	MAx 0.010		
	Operator_B site	10	0.0048	0.0042(1.90)	Max 0.011		
	Ground worker_B site	10	0.0098	0.0090(1.90)	Max 0.024		

4. Exposure Assessment of Total Volatile Organic Compunds(TVOCs) among Construction Painters[3)]

4.1. Introduction

Solvent exposures are related to adverse health disorders of skin, lung, kidney and nervous system (Winder and Turner, 1992). Painters exposed to organic solvents have high rates of cancers than other workers, increased prevalence of neurotoxic effects, and elevated rates of slips, trips, and falls (Wolford R, 1996). Construction painters are also known as significantly associated with respiratory symptoms and disease (White and Baker, 1988; Kaukiainen A, 2005) and neurotoxic symptoms (Fidler A, 1987). Although health effect is well reported, it is rare to find on-site studies for construction workers, especially construction painters, regarding personal exposure levels to hazards. The reason so few works have focused on this group is that most of the construction painters is highly mobile from one site to others and they tend to be temporary workers. Also their work environment is continuously changed in every construction sites day by day. The most frequently applied painting on building rooftops and ground parking lots is urethane resin waterproof painting, which accounts for more than 25% of construction waterproof painting in Korea (Wang, 2015). Urethane waterproof painting operations use various solvents for dissolving and dispersing urethane resins and hardners. In this

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chapter, the exposure concentrations of total volatile organic compounds (TVOCs) among construction urethane waterproof painters was evaluated.

4.2. Materials and methods

4.2.1 Exposure group selection and task description

Urethane waterproof painting works (Table 4-1) were monitored at eight construction workplaces. Five work types (urethane primer roller, mixing paint, urethane resin spread, painter assistant, workplace area) and five worksites (rooftop, ground floor, pilot floor, bathroom and swimming pool) were evaluated by using passive sampling devices (Organic Vapor Monitors, OVMs). Sampling was conducted twice between May and July 2014 and between April and June 2018.

Urethane waterproof painting work consists of primer and resin painting works. Primer was coated as the first layer, followed by the resin coating additionally as the outer second layer. Primer contains 50 ~ 60% solvents such as toluene, xylene, ethyl benzene (EB), methyl ethyl ketone (MEK), and ethyl acetate. Resins are normally composed of the main resin paint (about 9 kg) and the hardner (about 24 kg), and they might be formulated just before they were applied. Resin paint contains 30 ~ 35% of organic solvent; and hardner holds 50 ~ 60% of calcium carbonate, 15 ~ 25% of polypropylene glycol, and 10% of petroleum hydrocarbon.

Table 4-1. Target monitoring workplaces for waterproof painting work

Workplace	Sampling period	Sampling days	Sample numbers (workers)	Sampling location (worksite)	Work environment	Average sampling time (min)	Worksite area (㎡)	Average usage of paint (kg)
A	May, 2014	2 days	5	Rooftop	Outdoor	360	590	1100
B	May, 2014	1 day	10	Ground parking lot	Outdoor	120	600	1320
C	May, 2014	1 day	10	Swimming pool	Indoor	186	400	1000
D	April, 2018	2 days	10	Rooftop	Outdoor	201	495	1500
E	May, 2018	4 days	27	Rooftop	Outdoor	212	495	1200
F	May, 2018	2 days	8	Bathroom	Indoor	283	34	84
G	May, 2018	2 days	12	pilot floor	Semi_ Indoor	407	247	800
H	June, 2018	1 days	6	Ground parking lot	Outdoor	445	396	1100

4.2.2 Sampling and analytical methods

For the personal air monitoring of TVOCs, 3M 3500 OVM (Organic Vapor Monitor) passive sampling media (3M Co, USA) were introduced. Fifteen organic vapors were detected GC-FID (Gas chromatography with flame ionization detector). Analytical instruments and conditions are shown in Table 4-2. Thirteen chemicals including toluene, xylene, MEK, MIBK, benzene, EB, styrene, trichloroethylene (TCE), perchloroethylene (PCE), n-butyl acetate, iso-butyl acetate, sec-butyl acetate and tert-butyl acetate were selected. US Occupational Safety and Health Administration (US-OSHA) and/or National Institute for Occupational Safety and Health (US-NIOSH) had validated sampling and analytical methods for passive samplings. Additionally, n-hexane and acetone were targeted because the vapors had been identified frequently in domestic work environments. The manufacturer of OVM recommended passive sampling for these two compounds. Polar chemicals such as methanol and methyl acetate did not include in this monitoring program as the manufactures did not specify them in their recommended passive sampling methodology (3M Co., 2006).

4.2.3. Statistical analysis and calculation of EI (Exposure Index)

Exposure Index (EI) could be calculated by the following equation to express the combined effects of organic compounds (ACGIH, 2014). In the equation, C_i means the measured concentration of each organic compound and OEL_i denotes Occupational Exposure Limit (OEL) for the chemical vapors. For OELs, Korean Occupational Exposure Limits

(KOEL) and 2018 Threshold Limit Values (TLVs) of American Conference of Governmental Hygienists (ACGIH) was brought in as a reliable international workplace exposure recommendation.

$$EI = \frac{C_1}{OEL_1} + \frac{C_2}{OEL_2} + \cdots\cdots + \frac{C_n}{OEL_n}$$

The data distribution was examined for statistical normality by using Shapiro-Wilke's W-test. Non-parametric tests such as Kruskal Wallis analysis were performed to determine the concentration differences among various waterproof painting works using the PASW version 18.0 (IBM Inc., USA). SigmaPlot Version 14.0 (Systat Software Inc., USA) was available for construct figures in this study.

Table 4-2. Analytical Instrument and Conditions

Classification		First measurement (May, 2014)	Second measurement (May-June, 2018)
Instrument		GC 6890 (Agilent Technologies, USA)	GC 7890A (Agilent Technologies,USA)
Analytical condition	Detector	Flame Ionization Detector (FID)	Mass Spectrometer Detector (MSD) ; Agilent 5975C inert XL with Triple-Axis Detector
	Inlet	200℃, Column flow: 1 mℓ/min	270℃, Column flow: 1 mℓ/min
	Oven	40℃ (5 min) 10℃/min to 130℃ (1 min) 20℃/min to 230℃ for (7 min)	40℃ (5 min) 8℃/min to 250℃ (10 min)
	Column	DB-624 (60 m x 0.25 mm x 1.4 μm) DB-WAX (30 m x 0.25 mm x 1.0 μm)	HP-5MS (30 m x 0.25 mm x 0.25 μm)

4.3. Results

4.3.1 TVOCs concentration in waterproof painting work

Among 88 VOCs samples collected from the urethane waterproof painting work (Table 4-3, 4-4, 4-5. 4-6), toluene, xylene, methyl ethyl ketone, ethylbenzene, ethyl acetate, and butyl acetate were detected. GM (range) of each components is 18.72 (1.5 ~ 285.5) ppm, 8.27 (1.68 ~ 113.98) ppm, 0.18 (0.1 ~ 12.06) ppm, 2.92 (0.3 ~ 103.14) ppm, 1.23 (0.11 ~ 42.21) ppm and 0.93 (0.6 ~ 26.77) ppm, respectively. As a result of evaluating EI by applying Korea Occupational Exposure Limits (KOEL: MoEL, 2020), GM was 0.78 (GSD 2.53), and 34 samples (38.6%) exceeded OEL, and 12 samples (13.6%) exceeded two times of OEL. However, when calculating EI according to the exposure limits (Threshold Limit Values, TLVs: ACGIH, 2018) set by the American Conference of Governmental Industrial Hygienists (ACGIH), the OEL of toluene (50→20 ppm) and butyl acetate (150→50 ppm) and ethylbenzene (100→20 ppm) applied differently. Then, the GM of EI was 1.84, which was more than twice as high as the KOEL application result.

The chemical component that has the most significant influence on evaluation the mixed effect of solvents applied by KOEL was toluene, occupied about 75%, followed by xylene 17%, and ethyl benzene 6%. Twenty-five samples (28.4%) of toluene exceeded 50 ppm and ethyl-benzene and xylene also exceeded 100 ppm in each of the two samples.

4.3.2 TVOCs concentration by worksite, work types and work environment

The evaluation result of TVOCs is divided into the worksite, work type, and work environment (indoor/outdoor) (Figure 4-1 and Table 4-3). The GM (GSD) of EI value (applied to KOEL) by the worksite was highest in order of 1.4 (1.82) for bathroom > 1.37 (2.96) for swimming pool > 0.89 (1.48) for pilot floor > 0.82 (1.62) for ground floor > 0.57 (2.89) for rooftop. The EI values (applied to KOEL) by the worksites were statistically significantly different ($p<0.05$), but significantly lower only on the rooftop. The GM (GSD) of EI value (applied to ACGIH TLVs) by the worksite was highest in order of 3.12 (3.22) for swimming pool > 2.85 (1.98) for bathroom > 2.15 (1.47) for pilot floor > 1.98 (1.63) for ground floor > 1.38 (3.03) for rooftop. The EI values (applied to ACGIH TLVs) by the worksites were not statistically significantly different ($p=0.142$). According to the work type, the GM (GSD) of EI value (applied to KOEL) was highest in order of primer roller painting 1.2 (2.89) > urethane resin spreader painting 0.85 (2.05) > area sample in the workplace 0.83 (1.65) > mixing paint work 0.53 (3.35) > painting assistant 0.35 (3.08). However, the EI value by the work type was not statistically significantly different ($p>0.05$). By the work environment such as indoor, semi-indoor, and outdoor work, the GM (GSD) of EI value (applied to KOEL) is highest in order of 1.38 (2.41) for indoor work > 0.89 (1.48) for semi-indoor work > 0.63 (2.58) for outdoor work. The variability of concentration (GSD) was largest at the rooftop and swimming pool by worksites and mixing paint and paint assistant work by work types. The GM (GSD) of EI values integrating work type and work environment variables was highest at primer roller painting in a indoor work environment as 2.93 (1.84) applied to KOEL and 7.17 (1.87) applied to ACGIH TLVs.

Table 4-3. Geometric mean(GM) and geometric standard deviation(GSD) of TVOCs concentration by worksite, work type and work environment

Classification	n	Exposure index (S. Korea OEL)	Exposure index (ACGIH TLV)	Meyhyl ethyl ketones(ppm)	Ethyl acetate (ppm)	Toluene (ppm)	n Buthyl acatate (ppm)	Ethyl benzene (ppm)	Xylene (ppm)
OEL (S. Korea)		*1*	*1*	*200*	*400*	*50*	*150*	*100*	*100*
OEL (ACGIH)				*200*	*400*	*20*	*50*	*20*	*100*
Total	*88*	*0.78(2.53)*	*1.84(2.6)*	*0.18(3.61)*	*1.23(4.07)*	*18.72(4.44)*	*0.93(2.74)*	*2.92(3.86)*	*8.27(3.58)*
Worksite									
Rooftop	42	0.57(2.89)*	1.38(3.03)	0.13(2.22)	0.78(3.22)	10.11(5.91)	0.78(2.18)	2.21(4.05)	5.37(3.44)
Ground floor (parking lot)	16	0.82(1.62)	1.98(1.63)*	0.2(3.52)	0.88(2.92)	26.08(2.06)*	0.97(2.39)	3.95(3.8)	9.56(3.53)
pilot floor	12	0.89(1.48)*	2.15(1.47)*	< LOD	7.66(3.17)*	33.72(1.51)*	< LOD	5.6(1.58)*	11.06(1.72)
Bathroom floor	8	1.4(1.82)	2.85(1.98)	< LOD	1.24(3.83)	28.25(2.05)	7.16(3.95)	9.94(2.97)	53.55(2.14)
Swimming pool	10	1.37(2.96)	3.12(3.22)	2.04(5.02)	1.56(4.35)*	52.08(3.9)	< LOD	0.99(2.59)	6.36(2.89)
ANOVA analysis		$p<0.05$	$p=0.059$	$p<0.001$	$p<0.001$	$p<0.001$	$p<0.001$	$p<0.001$	$p<0.001$
Kruskal-Wallis rank test		$p<0.05$	$p=0.142$	$p<0.001$	$p<0.001$	$p=0.058$	$p<0.001$	$p<0.01$	$p<0.001$
Work type									
Primer roller painting	17	1.20(2.89)*	3.18(2.63)*	0.84(7.21)	2.3(4.52)	26.46(7.39)	0.6(1)	2.09(6.46)	5.26(3.69)
Mixing paint	10	0.53(3.35)*	1.12(3.68)*	0.1(1)	0.75(2.35)	11.96(5.91)*	1.07(2.98)	1.62(2.38)	7.47(3.53)*
Urethane resin spreader painting	34	0.85(2.05)	1.96(2.26)*	0.16(2.5)	0.9(4.31)	26.49(3.16)*	0.89(2.75)	2.7(3.13)	7.73(3.14)
Painter assistant	10	0.35(3.08)*	0.98(3.16)*	0.1(1)	1.52(4.93)	3.96(4.45)	0.6(1)	5.07(5.32)*	6.37(3.51)*
Area sample	17	0.83(1.65)	1.79(1.62)*	0.1(1)	1.46(3.17)	21.49(1.69)*	1.86(3.94)	4.88(2.65)*	18.36(3.7)*
ANOVA analysis		$p<0.05$	$p<0.05$	$p<0.001$	$p=0.141$	$p<0.01$	$p<0.01$	$p=0.124$	$p<0.05$
Kruskal-Wallis rank test		$p=0.058$	$p=0.065$	$p<0.001$	$p<0.05$	$p<0.05$	$p<0.01$	$p=0.110$	$p<0.05$
Environment									
Outdoor	58	0.63 (2.58)*	1.53 (2.68)*	0.15 (2.6)	0.81 (3.11)	13.13 (5)	0.83 (2.23)	2.6 (4.03)	6.29 (3.52)
Semi-indoor	12	0.89 (1.48)*	2.15 (1.47)*	< LOD	7.66 (3.17)*	33.72 (1.51)*	< LOD	5.6 (1.58)*	11.06 (1.72)
Indoor	18	1.38 (2.41)*	3.00 (2.61)*	0.53 (6.94)	1.41 (3.97)	39.68 (3.11)*	1.81 (4.68)	2.76 (4.64)*	16.39 (4.15)*
ANOVA anaiysis		$p<0.05$	$p<0.05$	$p<0.01$	$p<0.01$	$p<0.01$	$p<0.01$	$p=0.197$	$p<0.05$
Kruskal-Wallis rank test		$p=0.056$	$p<0.05$	$p<0.001$	$p<0.001$	$p<0.05$	$p<0.05$	$p=0.128$	$p<0.05$

* log-normal distribution

Table 4-3. Geometric mean (GM) and geometric standard deviation (GSD) of TVOCs concentration by worksite, work type and work environment_*continued*

Classification	n	Exposure index (S. Korea OEL)	Exposure index (ACGIH TLV)	Meyhyl ethyl ketones(ppm)	Ethyl acetate (ppm)	Toluene (ppm)	n Buthyl acatate (ppm)	Ethyl benzene (ppm)
OEL (S. Korea)		*1*	*1*	*200*	*400*	*50*	*150*	*100*
OEL (ACGIH)				*200*	*400*	*20*	*50*	*20*
Total	*88*	*0.78(2.53)*	*1.84(2.6)*	*0.18(3.61)*	*1.23(4.07)*	*18.72(4.44)*	*0.93(2.74)*	*2.92(3.86)*
Work type × Environment								
Primer roller painting × Outdoor	11	0.74 (2.54)*	2.04 (2.29)*	0.27 (4.15)	1.65 (5.73)	10.69 (6.71)	N.D.	4.31 (6.72)*
Primer roller painting × Indoor	6	2.93 (1.84)*	7.17 (1.87)*	6.41 (2.37)	4.27 (2.01)	139.27 (1.92)*	N.D.	0.55 (2.16)
Urethane resin painting × Outdoor	47	0.61 (2.61)*	1.42 (2.76)*	0.13 (2.13)	0.68 (2.43)	13.77 (4.72)	0.89 (2.4)	2.3 (3.46)
Urethane resin painting × Semi-indoor	12	0.89 (1.48)	2.15 (1.47)	N.D.	7.66 (3.17)	33.72 (1.51)*	N.D.	5.6 (1.58)
Urethane resin painting × Indoor	12	0.95 (2.11)*	1.94 (2.2)*	0.15 (1.89)	0.81 (3.69)*	21.18 (2.04)*	3.13 (5.16)	6.19 (3.05)*
ANOVA analysis		*p<0.01*	*p<0.01*	*p<0.001*	*p<0.001*	*p<0.01*	*p<0.001*	*p<0.01*
Kruskal-Wallis rank test		*p<0.01*	*p<0.01*	*p<0.001*	*p<0.001*	*p<0.01*	*p<0.001*	*p<0.01*

* log-normal distribution

Table 4-4. TVOCs Concentrations by worksites

Type of Worksite	Classification	Exposure Index (S. Korea OEL)	Exposure Index (ACGIH TLV)	Methyl ethyl ketone (ppm)	Ethyl acetate (ppm)	Toluene (ppm)	n Buthyl acatate (ppm)	Ethyl benzene (ppm)	Xylene (ppm)
OEL (S. Korea)		*1*	*1*	*200*	*400*	*50*	*150*	*100*	*100*
OEL (ACGIH)				*200*	*400*	*20*	*50*	*20*	*100*
Rooftop	n	42	42	42	42	42	42	42	42
	AM±SD	0.92±0.85	2.33±2.24	0.25±0.6	2.99±8.58	34.52±44.84	1.38±2.68	8.9±22.46	12.64±19.81
	GM(GSD)	0.57(2.89)	1.38(3.03)	0.13(2.22)	0.78(3.22)	10.11(5.91)	0.78(2.18)	2.21(4.05)	5.37(3.44)
	Median	0.56	1.34	0.1	0.5	11.68	0.6	1	2.36
	Range	0.07~2.96	0.16~7.4	0.1~3.85	0.5~39.63	1.5~146.41	0.6~13.99	0.52~103.14	1.93~82.79
Ground floor (parking lot)	n	16	16	16	16	16	16	16	16
	AM±SD	0.95±0.7	2.27±1.56	0.51±0.83	2.18±4.97	33.66±27.71	1.52±1.77	7.21±6.28	18.46±21.51
	GM(GSD)	0.82(1.62)	1.98(1.63)	0.2(3.52)	0.88(2.92)	26.08(2.06)	0.97(2.39)	3.95(3.8)	9.56(3.53)
	Median	0.82	1.78	0.1	0.5	25.13	0.6	5.66	10.15
	Range	0.48~3.4	1.06~7.64	0.1~3.03	0.5~20.42	7.74~118.21	0.6~6.05	0.47~19.68	2~81.44
pilot floor	n	12	12	12	12	12	12	12	12
	AM±SD	0.95±0.38	2.3±0.9	< LOD	13.45±14.11	36.49±15.71	< LOD	6.07±2.27	12.27±4.84
	GM(GSD)	0.89(1.48)	2.15(1.47)	< LOD	7.66(3.17)	33.72(1.51)	< LOD	5.6(1.58)	11.06(1.72)
	Median	0.88	2.14	< LOD	6.76	31.65	< LOD	5.95	12.23
	Range	0.43~1.7	1.07~4.08	< LOD	1.32~42.21	18.45~69.56	< LOD	1.78~10.42	2.56~21.16
Bathroom floor	n	8	8	8	8	8	8	8	
	AM±SD	1.59±0.66	3.34±1.56	< LOD	3.14±5.3	34.65±22.86	12.36±9.78	13.72±7.65	66.46±39.59
	GM(GSD)	1.4(1.82)	2.85(1.98)	< LOD	1.24(3.83)	28.25(2.05)	7.16(3.95)	9.94(2.97)	53.55(2.14)
	Median	1.89	3.63	< LOD	0.5	32.77	11.8	16.09	71.4
	Range	0.48~2.18	0.77~5.32	< LOD	0.5~15.85	8.08~80.64	0.6~26.77	1~21.2	17.11~113.98
Swimming pool	n	10	10	10	10	10	10	10	10
	AM±SD	2.19±1.99	5.33±4.99	5.04±5.36	3.19±3.08	102.4±101.4	< LOD	1.39±0.98	9.53±7.06
	GM(GSD)	1.37(2.96)	3.12(3.22)	2.04(5.02)	1.56(4.35)	52.08(3.9)	< LOD	0.99(2.59)	6.36(2.89)
	Median	1.37	3.28	2.13	1.74	61.61	< LOD	1.48	10.31
	Range	0.41~5.81	0.85~14.39	0.35~12.06	0.11~7.05	10.92~285.5	< LOD.	0.3~2.66	1.68~18.73
ANOVA analysis		*p<0.05*	*p=0.059*	*p<0.001*	*p<0.001*	*p<0.001*	*p<0.001*	*p<0.001*	*p<0.001*
Kruskal-Wallis rank test		*p<0.05*	*p=0.142*	*p<0.001*	*p<0.001*	*p=0.058*	*p<0.001*	*p<0.01*	*p<0.001*

Table 4-5. TVOCs Concentrations by work types

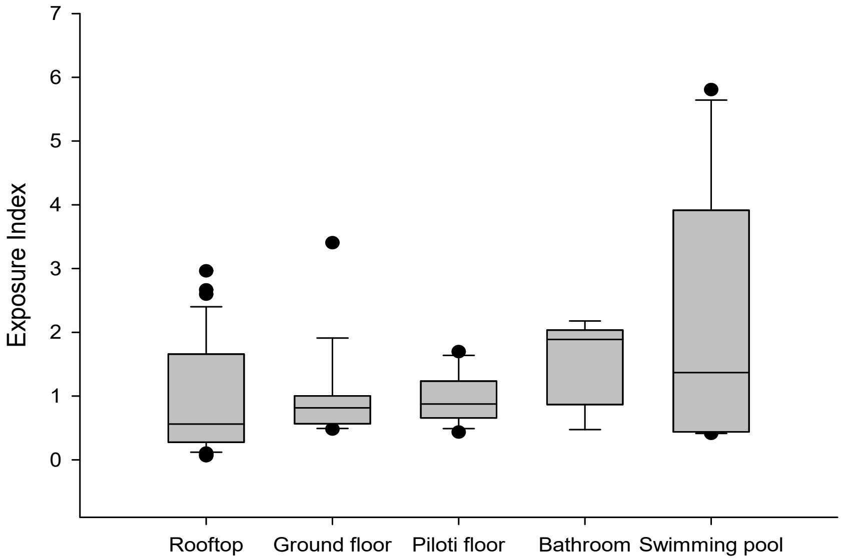
Work type	Classification	Exposure Index (S. Korea OEL)	Exposure Index (ACGIH TLV)	Methyl ethyl ketone (ppm)	Ethyl acetate (ppm)	Toluene (ppm)	n Buthyl acatate (ppm)	Ethyl benzene (ppm)	Xylene (ppm)
OEL (S. Korea)		*1*	*1*	*200*	*400*	*50*	*150*	*100*	*100*
OEL (ACGIH)				*200*	*400*	*20*	*50*	*20*	*100*
Primer roller painting	n	17	17	17	17	17	17	17	17
	AM±SD	1.87±1.67	4.7±4.05	3.33±4.59	6.35±10.04	78.95±85.44	< LOD	11.3±25.12	14.36±26.01
	GM(GSD)	1.2(2.89)	3.18(2.63)	0.84(7.21)	2.3(4.52)	26.46(7.39)	< LOD	2.09(6.46)	5.26(3.69)
	Median	1.27	3.14	1.32	1.74	52.18	< LOD	1	2.33
	Range	0.16~5.81	0.53~14.39	0.1~12.06	0.5~39.63	1.5~285.5	< LOD	0.3~103.14	1.68~82.79
Mixing paint	n	10	10	10	10	10	10	10	10
	AM±SD	0.9±0.83	2.09±2.13	< LOD	1.16±1.4	35.43±44.67	2.35±4.23	2.5±2.94	14.25±16.35
	GM(GSD)	0.53(3.35)	1.12(3.68)	< LOD	0.75(2.35)	11.96(5.91)	1.07(2.98)	1.62(2.38)	7.47(3.53)
	Median	0.76	1.5	< LOD	0.5	15.79	0.6	1	10.51
	Range	0.07~2.66	0.16~6.66	< LOD	0.5~4.18	1.5~131.43	0.6~13.99	1~8.58	2~54.17
Urethane resin spreader painting	n	34	34	34	34	34	34	34	34
	AM±SD	1.1±0.79	2.65±2	0.32±0.66	4.4±10.32	43.93±40.64	2.22±5.12	5.08±5.87	14.01±17.56
	GM(GSD)	0.85(2.05)	1.96(2.26)	0.16(2.5)	0.9(4.31)	26.49(3.16)	0.89(2.75)	2.7(3.13)	7.73(3.14)
	Median	0.74	1.74	0.1	0.5	25.1	0.6	2.29	10.51
	Range	0.32~2.96	0.41~7.4	0.1~3.85	0.11~42.21	1.5~146.41	0.6~26.77	0.52~21.2	1.93~96.1
Painter Assistant	n	10	10	10	10	10	10	10	10
	AM±SD	0.6±0.65	1.69±1.89	< LOD	5.96±12.24	12.84±23.01	< LOD	17.41±31.54	14.61±24.76
	GM(GSD)	0.35(3.08)	0.98(3.16)	< LOD	1.52(4.93)	3.96(4.45)	< LOD	5.07(5.32)	6.37(3.51)
	Median	0.38	0.97	< LOD	0.5	1.5	< LOD	5.34	6.25
	Range	0.07~1.99	0.16~6.17	< LOD	0.5~39.63	1.5~73.38	< LOD	1~103.14	2~82.79
Area Sample	n	17	17	17	17	17	17	17	17
	AM±SD	0.94±0.53	2.01±1.03	< LOD	2.96±4.44	24.06±10.72	4.66±6.75	7.17±6.11	34.8±36.29
	GM(GSD)	0.83(1.65)	1.79(1.62)	< LOD	1.46(3.17)	21.49(1.69)	1.86(3.94)	4.88(2.65)	18.36(3.7)
	Median	0.71	1.71	< LOD	1.23	24.4	0.6	5.35	21.82
	Range	0.43~1.93	0.77~3.99	< LOD	0.5~18.24	7.74~43.86	0.6~20.9	1~19.95	2~113.98
ANOVA analysis		$p<0.05$	$p<0.05$	$p<0.001$	$p=0.141$	$p<0.01$	$p<0.01$	$p=0.124$	$p<0.05$
Kruskal-Wallis rank test		$p=0.058$	$p=0.065$	$p<0.001$	$p<0.05$	$p<0.05$	$p<0.01$	$p=0.110$	$p<0.05$

Table 4-6. TVOCs Concentrations by work environments

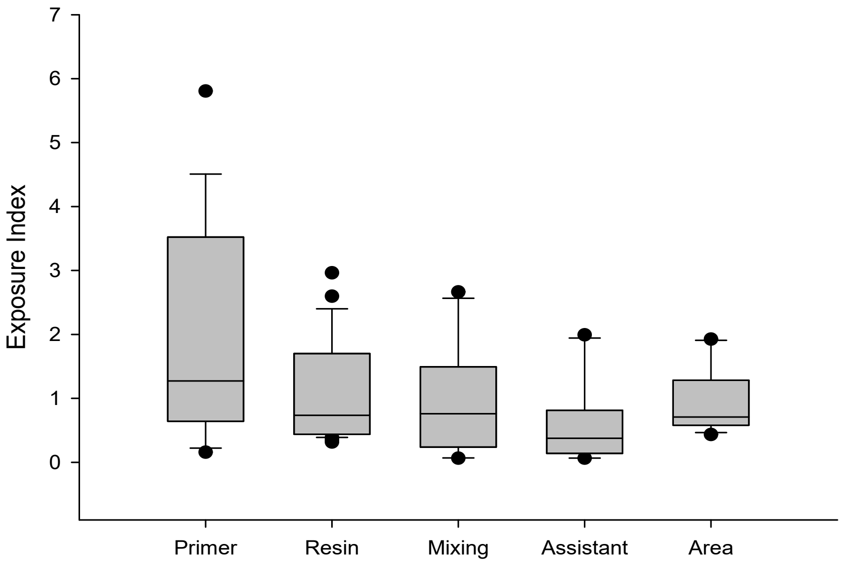
Work environment	Classification	Exposure Index (S. Korea OEL)	Exposure Index (ACGIH TLV)	Methyl ethyl ketone (ppm)	Ethyl acetate (ppm)	Toluene (ppm)	n Buthyl acatate (ppm)	Ethyl benzene (ppm)	Xylene (ppm)
OEL (S. Korea)		*1*	*1*	*200*	*400*	*50*	*150*	*100*	*100*
OEL (ACGIH)				*200*	*400*	*20*	*50*	*20*	*100*
Total	n	88	88	88	88	88	88	88	88
	AM±SD	1.14±1.03	2.75±2.57	0.81±2.37	4.3±8.99	42.36±51.82	2.21±4.71	7.79±16.09	18.19±25.33
	GM(GSD)	0.78(2.53)	1.84(2.6)	0.18(3.61)	1.23(4.07)	18.72(4.44)	0.93(2.74)	2.92(3.86)	8.27(3.58)
	Median	0.74	1.78	0.1	0.5	24.31	0.6	2.29	9.27
	Range	0.07～5.81	0.16～14.39	0.1～12.06	0.11～42.21	1.5～285.5	0.6～26.77	0.3～103.14	1.68～113.98
Outdoor	n	58	58	58	58	58	58	58	58
	AM±SD	0.93±0.81	2.32±2.06	0.32±0.67	2.77±7.72	34.29±40.6	1.42±2.45	8.44±19.33	14.25±20.27
	GM(GSD)	0.63(2.58)	1.53(2.68)	0.15(2.6)	0.81(3.11)	13.13(5)	0.83(2.23)	2.6(4.03)	6.29(3.52)
	Median	0.59	1.46	0.1	0.5	17.9	0.6	1	4.46
	Range	0.07～3.4	0.16～7.64	0.1～3.85	0.5～39.63	1.5～146.41	0.6～13.99	0.47～103.14	1.93～82.79
Semi_Indoor	n	12	12	12	12	12	12	12	12
	AM±SD	0.95±0.38	2.3±0.9	< LOD.	13.45±14.11	36.49±15.71	< LOD	6.07±2.27	12.27±4.84
	GM(GSD)	0.89(1.48)	2.15(1.47)	< LOD	7.66(3.17)	33.72(1.51)	< LOD	5.6(1.58)	11.06(1.72)
	Median	0.88	2.14	< LOD	6.76	31.65	< LOD	5.95	12.23
	Range	0.43～1.7	1.07～4.08	< LOD	1.32～42.21	18.45～69.56	< LOD	1.78～10.42	2.56～21.16
Indoor	n	18	18	18	18	18	18	18	18
	AM±SD	1.92±1.54	4.45±3.9	2.85±4.64	3.17±4.07	72.29±82.82	5.83±8.69	6.87±8.02	34.84±38.98
	GM(GSD)	1.38(2.41)	3(2.61)	0.53(6.94)	1.41(3.97)	39.68(3.11)	1.81(4.68)	2.76(4.64)	16.39(4.15)
	Median	1.76	3.49	0.36	1.12	41.9	0.6	2.35	16.88
	Range	0.41～5.81	0.77～14.39	0.1～12.06	0.11～15.85	8.08～285.5	0.6～26.77	0.3～21.2	1.68～113.98
ANOVA anaiysis		*p<0.05*	*p<0.05*	*p<0.01*	*p<0.01*	*p<0.01*	*p<0.01*	*p=0.197*	*p<0.05*
Kruskal-Wallis rank test		*p=0.056*	*p<0.05*	*p<0.001*	*p<0.001*	*p<0.05*	*p<0.05*	*p=0.128*	*p<0.05*

Table 4-7. TVOCs Concentrations by work types × work environments

Type of Workplace		Classification	Exposure Index (S. Korea OEL)	Exposure Index (ACGIH TLV)	Methyl ethyl ketone (ppm)	Ethyl acetate (ppm)	Toluene (ppm)	n Buthyl acatate (ppm)	Ethyl benzene (ppm)	Xylene (ppm)
OEL (S. Korea)			*1*	*1*	*200*	*400*	*50*	*150*	*100*	*100*
OEL (ACGIH)					*200*	*400*	*20*	*50*	*20*	*100*
Primer painting	Outdoor	n	11	11	11	11	11	11	11	11
		AM±SD	1.06±0.94	2.75±2.24	0.7±0.95	7.06±12.5	33.26±37.1	N.D.	17.08±30.09	19.62±31.41
		GM(GSD)	0.74 (2.54)	2.04 (2.29)	0.27 (4.15)	1.65 (5.73)	10.69 (6.71)	N.D.	4.31 (6.72)	6.74 (4.32)
		Median	0.93	2.31	0.1	0.5	33.77	N.D.	7.88	4.46
		Range	0.16～3.4	0.53～7.64	0.1～3.03	0.5～39.63	1.5～118.21	N.D.	0.47～103.14	2～82.79
	Indoor	n	6	6	6	6	6	6	6	6
		AM±SD	3.37±1.73	8.28±4.32	8.16±4.74	5.05±2.58	162.71±87.16	N.D.	0.72±0.59	4.71±4.34
		GM(GSD)	2.93 (1.84)	7.17 (1.87)	6.41 (2.37)	4.27 (2.01)	139.27 (1.92)	N.D.	0.55 (2.16)	3.33 (2.41)
		Median	3.73	9.21	10.3	6.38	181.92	N.D.	0.38	2.11
		Range	1.36～5.81	3.27～14.39	1.94～12.06	1.73～7.05	61.36～285.5	N.D.	0.3～1.52	1.68～10.61
	T test		*p<0.05*	*p<0.05*	*p<0.001*	*p=0.244*	*p<0.05*	-	*p<0.05*	*p=0.302*
Resin painting	Outdoor	n	47	47	47	47	47	47	47	47
		AM±SD	0.9±0.78	2.21±2.03	0.23±0.57	1.76±5.87	34.53±41.75	1.61±2.69	6.41±15.63	12.99±16.91
		GM(GSD)	0.61 (2.61)	1.42 (2.76)	0.13 (2.13)	0.68 (2.43)	13.77 (4.72)	0.89 (2.4)	2.3 (3.46)	6.19 (3.4)
		Median	0.58	1.39	0.1	0.5	17.75	0.6	1	4.46
		Range	0.07～2.96	0.16～7.4	0.1～3.85	0.5～39.63	1.5～146.41	0.6～13.99	0.52～103.14	1.93～82.79
	Semi-indoor	n	12	12	12	12	12	12	12	12
		AM±SD	0.95±0.38	2.3±0.9	N.D.	13.45±14.11	36.49±15.71	N.D.	6.07±2.27	12.27±4.84
		GM(GSD)	0.89 (1.48)	2.15 (1.47)	N.D.	7.66 (3.17)	33.72 (1.51)	N.D.	5.6 (1.58)	11.06 (1.72)
		Median	0.88	2.14	N.D.	6.76	31.65	N.D.	5.95	12.23
		Range	0.43～1.7	1.07～4.08	N.D.	1.32～42.21	18.45～69.56	N.D.	1.78～10.42	2.56～21.16
	Indoor	n	12	12	12	12	12	12	12	12
		AM±SD	1.2±0.77	2.53±1.73	0.19±0.13	2.23±4.44	27.09±21.4	8.44±9.71	9.95±8.26	49.9±39.96
		GM(GSD)	0.95 (2.11)	1.94 (2.2)	0.15 (1.89)	0.81 (3.69)	21.18 (2.04)	3.13 (5.16)	6.19 (3.05)	36.34 (2.31)
		Median	1.13	2.37	0.1	0.5	18.32	3.08	7.78	25.81
		Range	0.41～2.18	0.77～5.32	0.1～0.38	0.11～15.85	8.08～80.64	0.6～26.77	1～21.2	15.66～113.98
	ANOVA analysis		*p=0.169*	*p=0.283*	*p=0.294*	*p<0.001*	*p=0.1*	*p<0.001*	*p<0.05*	*p<0.001*


7
6
5
4
3
2
1
0
Exposure Index
Rooftop
Ground floor
Piloti floor
Bathroom
Swimming pool

(a)


7
6
5
4
3
2
1
0
Exposure Index
Primer
Resin
Mixing
Assistant
Area

(b)

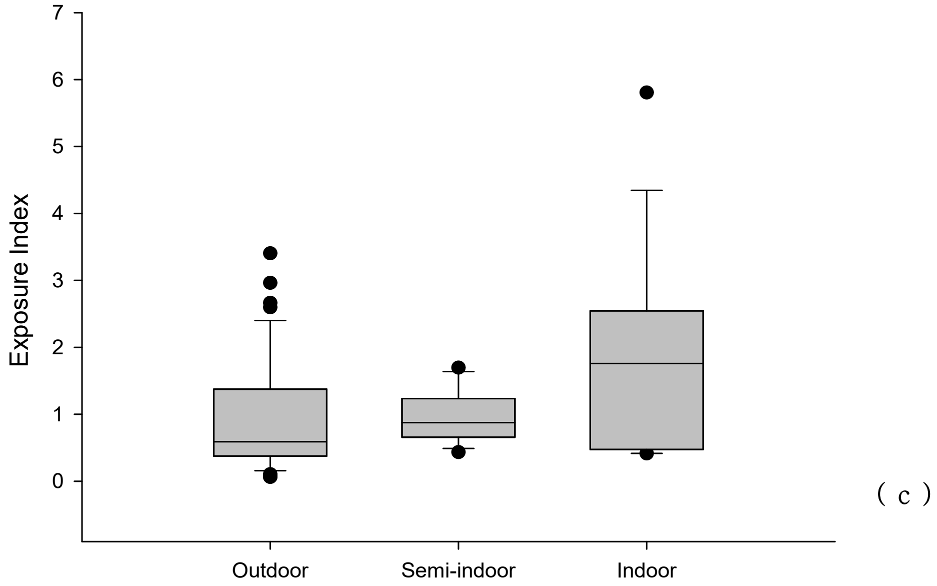


Figure 4-1. Exposure Index based on KOEL of TVOCs by (a) worksite, (b) work type and (c) work environment

※ The boxes show the 25th and 75th percentiles and whiskers indicate 10th and 90th percentiles. Median is indicated by the line inside the box.

4.4. Discussion

The concentration of TVOCs of the urethane waterproof painting work at rooftop, ground parking lot, pilot floor, household bathroom, and underground swimming pool at eight new apartment construction sites were evaluated. The GM of the exposure index (EI) of TVOCs was about 78% level of KOEL, and the samples exceeding OEL accounted for about 38.6% of the total samples, which is the concentration that requires improvement of the working environment. Moreover, if EI was calculated according to the US ACGIH TLVs, the GM of EI was 1.84, which exceeded twice the OEL. The chemical substance with the greatest influence on the EI value was toluene, and the GM concentration of toluene was 18.72 ppm, but the range was very extensive with GSD 4.44. It means that some samples exceeding the OEL may also occur.

Choi et al.(2000) studied the exposure concentration of TVOCs in the apartment interior and modification painting work. They reported that TVOCs concentration of entire painting workers (n=14) exceeded OEL. The AM EI corresponding values of TVOCs for painters, painting assistants, spray painters, brush painters, and area samples after finishing the painting work were 7.97, 3.36, 11.50, 2.12, and 3.27, respectively.

An et al.(2019) reported the concentration of TVOCs evaluated in shipyard painting workers. The GM EI of spray painting workers was 0.71 (with KOEL), similar to the exposure level of urethane waterproof painters in this study. Generally, TVOCs are known to have a high exposure concentration when applying paint by spray method (Keer et al., 2018). However, the urethane waterproof painting work in this study showed similar exposure concentration levels even though it was done using rollers and spreaders. Uang et al. (2006) studied the concentration of TVOCs in painting the airplane. The study reported that the toluene concentration (AM ± SD) was 6.55 ± 2.44 ppm (Boeing 747-400) and 10.72 ± 8.28 ppm (Airbus A300) for primer painting, and 5.93 ± 7.23 ppm (Boeing 747-400) and 5.16 ± 2.81 ppm (Airbus A300) for surface painting work.

Riala et al.(1984) reported the concentrations in the highway and subway steel bridge painting, and TVOCs as solvent naphtha was 670±138 ppm for spray painting and 11.5±16.2 ppm for roller and brush painting. In the indoor painting work, without a mechanical ventilation system, TVOCs concentration were 235 ppm for spray painting and 194 ppm for roller and brush painting. Also, reported that when working with winds from doors and windows, TVOCs concentration would be decreased to about 38 ppm compared to the painting in a relatively confined space. Qian et al. (2010) reported the TVOCs concentration of bridge painting using OVM (3M OVM 3500). They showed the results of 58 task-based samples (assessment only during the operation time) and 30 full-shift samples (assessment during the day for 8 hours). In the task-based samples of spray painting (n=18), the results showed that AM±SD of aromatics, esters, ketones, alkanes, and TVOCs were 410.1±242.1 ppm, 209.0±300.6 ppm, 50.1±80.8 ppm, less than 0.3 ppm, and 669.5±138.3 ppm. In task-based samples of brush and roller painting (n=39), AM±SD of aromatics was 6.5±9.3 ppm and 1.0±2.6 ppm for esters, 0.9±0.4 ppm for ketones, <0.3±6.9 ppm for alkanes, 11.5±2.9 ppm for TVOCs. In dfull-shift samples of spray painting (n=12), the results showed that AM±SD for aromatics, aromatics, esters, ketones, alkanes, and TVOCs were 87.3±60.6 ppm, 23.7±35.4 ppm, 0.2 ± 0.2 ppm, less than 0.4 ppm, and

112 ± 43.9 ppm, respectively. In full-shift samples of brush and roller painting (n=18), aromatics recorded 1.1±1.2 ppm, with <0.1 ppm for esters, 0.3±0.8 ppm for ketones, 1.7±0.9 ppm for alkanes, and 3.2±1.7 ppm. Task-based samples that might correspond to real-time projected dose showed relatively high concentration levels compare to those of full-shift samples that might be represented as TWA. Therefore, any exposure monitoring program for construction workers who may have irregular working schedules day by day might require more rigorous work-activity analysis with several days measurements to construct real average daily exposure profiles to compare OELs. As spray painting used a large amount of organic solvents per working time, it could been seen that higher solvent exposures could happen for spraying workers than brushing painter.

When estimating the past exposure concentration levels, we should consider the painting method (spray, roller, brush), painting time, and wearing respiratory protective equipment. Wang SW et al. (2011) reported that the most influential environmental variables of TVOCs concentrations were the painting method (spray, roller, brush) and painting time. In addition, spray painting while wearing respiratory protective equipment has higher TVOCs concentrations than roller and brush type painting even without wearing respiratory protective equipment. Exposure status of each era was also analyzed as a variable affecting TVOCs concentration due to whether or not to wear respiratory protection equipment. It was reported that the pre-1990s TVOCs concentrations were three times higher than the levels since the 1990s.

This study found that many construction painters could be over-exposed to volatile organic solvents during their various tasks. It is well-known that organic solvents such as xylene, acetone, n-hexane, styrene, MEK, and MIBK gave hazards to the human eye, skin, respiratory tracks, central and peripheral nervous system. Especially toluene may provide risks for pregnant women and embryos. Ethylbenzene could cause kidney damage and cochlear impairment to human (ACGIH, 2014).

4.5. Conclusions

In this chapter, We recognize that the construction painting has complex combinations of exposure profiles to organic solvents and reproductive toxins. The TVOCs concentration levels in many of the painting tasks might exceed OEL extensively. The highest TVOCs concentration was reported at primer painting tasks in an indoor workplace. The most influential variables were work environment (indoor vs. outdoor) and a solvent content of the paint. Although the results were limited to our studied samples because the exposure levels of construction workplace have large variations by each task, construction painters essentially needed to be protected from chemical agents during the painting works. Construction painters required to be protected from chemical agents by applying the ventilation system, substituting paints with less toxic substances, and using personal protective devices with an appropriate protection. There should be further studies on methods to improve the hazardous working environment. During any work monitoring programs for construction sites, data of the detailed work status such as real working time, chemical usages per day, specific working method and types of personal protective equipment should be considered to identify the workers actual exposure status.

5. Exposure Assessment of Welding Fumes and Metals among Construction Welders[4)]

5.1. Introduction

Construction welders are constantly exposed to welding fumes even if they move from place to place. Welders are at risk of developing occupational diseases such as Parkinson's disease and nasal septum perforation due to the manganese and chromium components in welding fumes. (Kim et al., 1997; Jeon, 2001).

Building construction uses different types of steel for different purposes. Large-scale buildings use high-strength steel to withstand earthquakes and collapse, and high-rise buildings use refractory and ultra-high tensile steel to withstand fires. High-strength steel is known to contain chromium and high-tensile steel contains copper and nickel. Marine building structure use steel with copper, phosphorus, chromium, nickel, and titanium oxides to prevent rust (Han & Lee, 1995). The concentration of hazardous substances in welding fumes and metals may vary depending upon the base metal, welding technique, ventilation condition, and area of the workplace. In mild steel welding, iron, manganese, and copper exposure is usually high, while chromium and nickel exposure is high in stainless steel welding (Kang et al., 2007).

Many studies have conducted assessments of exposure to welding

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fumes in the steel industry (Lee et al., 2000), shipbuilding industry (Kim & Song, 1991; Shin et al., 1998; Kwag & Paik, 1997; Kang et al., 2007), heavy equipment manufacturing (Jeong et. al., 2002), automobile-related industries (Choi et al., 1999), and welding practice rooms (Hwang et al., 2001). However, no study has assessed the exposure to welding fumes at construction sites. According to the Korea Construction Workers' Association data, 18,318 workers are estimated to be employed at construction sites, but more are expected to be engaged in welding work at construction sites.

In this chapter, welding fumes and metals generated by various tasks in the construction industry were investigated to assess and prevent occupational diseases in welders and establish health management plans for construction welders.

5.2. Materials and methods

5.2.1 Exposure group selection and task description

The evaluation was conducted from March to June 2015 on eight construction sites, including three apartment construction sites, two office construction sites, one large scale building (hospital) construction site, one chemical plant construction site, and one incineration plant construction site. Welding tasks evaluated at each construction site were classified into general building piping welders, chemical plant piping welders, boiler manufacturing welders, steel welders, metal finishing welders, and other welders. The exposure concentrations of the welding fumes and the metals (manganese, chromium, copper, iron oxide, aluminum, nickel, lead, zinc oxide) contained in the fume were evaluated by each task. Table 5-1 shows the welding base materials, welding techniques, and the number of samples for each target monitoring workplace.

Table 5-1. Target monitoring workplace

Task	n	Building type	Welding material	Welding technique	Work place
Pipefitter _General Building	21	Apartment office	Zinc galvanized pipe	SMAW	Indoor
Pipefitter _Chemical Plant	84	Chemical plant	Stainless Steel Carbon Steel Alloy	TIG	Outdoor
Boilermaker	33	Incinerator plant	Carbon Steel	CO_2	Outdoor
Ironworker	9	Steel structure	Carbon Steel	CO_2	Outdoor
Metal finishing welder	35	Hospital	Carbon Steel	SMAW	In/Outdoor
Not classified	24	-	-	SMAW/ TIG	In/Outdoor

※ SMAW, Shielded Metal Arc Welding; TIG, Tungsten Inert Gas; CO_2, CO_2 Arc Welding

5.2.2 Sampling and analysis

Sampling methods

Gravimetrically analyzed PVC filter (37 mm, pore 5 μm, SKC Inc., USA) was mounted in a 37 mm 3-piece cassette and connected to a pump (Escort Elf Pump; MAS, USA) with a flow rate of 2 L/min. The sample was taken for more than six hours a day. The pumps were pre-and post-calibrated using a bubble calibrator (standard flow: 30 cc to 6 L/min; Gillian Corp. USA). Measurements were taken in the breathing zone outside the welding shield mask to improve the working environment.

Gravimetric analysis of welding fume

For the gravimetric analysis of welding fume, PVC filters were dried in a desiccator for over a day before sampling, stabilized in the gravimetric analysis chamber for > 2 hours, 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 the same as pre-filters.

Metals Analysis

Metals were analyzed using Inductively Coupled Plasma (iCAP6000 series, Thermo Scientific, UK) by the NIOSH(National Institute of Occupational Safety and Health) manual of analysis method (NMAM) # 7304. The sampled filters were placed in a 30 ml microwave vessel; 1 ml of concentrated nitric acid was added and capped. The vessel was placed in a microwave (MARS Xpress, CEM Corp., USA) and treated at 140℃ for 15 minutes to extract metals. The liquid in the vessel was transferred to a 20 ml volumetric flask, and the vessel was washed three times with deionized water, placed in a volumetric flask, and used as an analytical sample at the final scale with deionized water. The metal analysis was performed by injecting a sample into an autosampler (ASX-520 autosampler, CETAC, USA) and analyzed using an inductively coupled plasma (iCAP6000 series, Thermo Scientific, UK). Sample analysis was carried out by organizations that maintain proficiency in the American Industrial Hygiene Association (AIHA) quality analytical testing programs.

5.2.3 Statistical analysis

The normality test of the data examined the distribution characteristics, and there were evaluation groups that did not follow the normal distribution or the log-normal distribution. Therefore, both mean values were presented as arithmetic mean (AM) and geometric mean (GM). PASW version 18.0 was used for statistical analysis. Data using the IH DataStastics program developed by the American Industrial Hygiene Association(AIHA) calculated the probability of exceeding OEL from occupational exposure assessment results using the Bayesian statistical technique.

5.3. Results

5.3.1 Welding fume and metal concentration by welding task

Of the 206 samples collected from eight construction sites, including apartments, office buildings, a hospital and chemical and incineration plants, 182 samples can be classified as five welding tasks (pipefitters in general building, pipefitters in chemical plant, boilermakers, ironworkers, and metal finishing welders). The exposure concentrations of welding fumes and metals (manganese, chromium, copper, iron oxide, aluminum, nickel, lead, zinc oxide) by welding tasks were evaluated and shown in Table 5-2.

Pipefitter_general building (n=21) performed shielded metal arc welding (SMAW) with a galvanized pipe used in the building's water supply pipes. Most of the work was done in underground or indoor spaces. As a result, the welding fume concentration was 4.75 mg/m^3, manganese 0.07 mg/m^3, chromium 3.06 $\mu g/m^3$, copper 1.61 $\mu g/m^3$, iron oxide 0.44 mg/m^3, aluminum 0.021 mg/m^3, nickel 0.03 $\mu g/m^3$, lead 6.73 $\mu g/m^3$, and zinc oxide 1.22 mg/m^3. About 57% (n=12) of the welding fumes, 5% (n=1) of zinc oxide and 5% (n=1) of lead samples exceeded the exposure limit. Using the Bayesian statistical technique, the probability of exceeding OEL was 48.23%, 14.45%, 9.04%, and 6.37% in welding fume, zinc oxide, lead, and iron oxide concentration, respectively. Pipefitter_chemical plant (n=84) performed TIG (Gas Tungsten Arc Welding, GTAW) welding with stainless steel, alloy, and carbon steel. All work was carried out outdoors, and the exposure concentrations of welding fumes and metals were lower than that of other welding tasks. As a result, welding fume concentration was 0.71 mg/m³, manganese 0.0028 mg/m³, chromium 0.41 μg/m³, copper 1.15 μg/m³, iron oxide 0.079 mg/m³, aluminum 0.0056 mg/m³, nickel 0.17 μg/m³, lead 0.11 μg/m³ and zinc oxide 0.057 mg/m³. About 8% (n = 7) of the welding fume samples exceeded OEL, and none of the metals exceeded OEL. Incineration plant boilermakers (n=33) performed the welding of carbon dioxide (CO_2) with carbon steel, and most of the work was carried out outdoors. The results of boilermakers showed that welding fume concentration was 1.38 mg/m³, manganese 0.04 mg/m³, chromium 0.5 μg/m³, copper 0.49 μg/m³, iron oxide 0.19 mg/m³, aluminum 0.0069 mg/m³, nickel 0.04 μg/m³, lead 0.16 μg/m³, and zinc oxide 0.022 mg/m³. Approximately 15% (n=5) of the welding fume samples exceeded OEL, and the metals of the welding fume did not exceed OEL. Calculating the likelihood of exceeding OEL, the probability of welding fume and manganese exceeding OEL was 6.79% and 2.43%, respectively. Ironworkers (n=9) performed the carbon dioxide (CO_2) welding with carbon steel, and most of the work was carried out outdoors. The results of ironworkers showed that welding fume concentration was 3.77 mg/m³, manganese 0.47 mg/m³, chromium 6.03 μg/m³, copper 3.22 μg/m³, iron oxide 1.32 mg/m³, aluminum 0.027 mg/m³, nickel 0.03 μg/m³, lead 4.40 μg/m³ and zinc oxide 0.0098 mg/m³. Approximately 40% (n = 4) of the welding fume samples exceeded OEL, and one out of nine lead samples exceeded OEL. Calculating the probability of exceeding OEL, the likelihood of welding fume, manganese, lead, and iron oxide exceeding OEL was 31.8%, 3.69%, 4.89%, and 0.30%, respectively. The metal finish welder (n=35) performed the SMAW welding with carbon steel and galvanized pipes. Most of the work was carried out indoors. The average daily welding time was 2 ~ 3 hours, which was short and irregular. The concentration levels of welding fume and metals were mostly less than 10% of OEL.

Table 5-2. Welding fume and metals concentrations by construction welding tasks

Hazards (OEL)		Tasks				
		Pipefitter _General Building)	Pipefitter _Chemical Plant	Boilermaker	Ironwork	Metal Finishing (Metal Interior)
Welding Fume (5 mg/m³)	Detected n/n	21/21	84/84	33/33	9/9	35/35
	AM±SD	7.97±10.88	1.39±2.25	2.00±1.83	4.34±2.20	0.97±0.58
	GM(GSD)	4.75 (3.15)	0.71 (2.89)	1.38 (2.37)	3.77 (1.82)	0.78 (2.07)
	Range	0.16～53.11	0.096～11.76	0.35～6.22	1.50～7.18	0.152～2.32
	95%ile	31.36	4.07	5.71	10.10	2.59
	Exc Frac(%)	48.23 %	3.29 %	6.79 %	31.8 %	0.55 %
Manganese (Fume) (1 mg/m³)	Detected n/n	21/21	83/84	33/33	9/9	33/35
	AM±SD	0.12±0.12	0.010±0.048	0.11±0.16	0.51±0.20	0.0096±0.011
	GM(GSD)	0.07 (4.56)	0.0028 (4.08)	0.04 (5.10)	0.47 (1.52)	0.0037 (6.91)
	Range	0.0004～0.53	N.D.～0.44	0.0021～0.60	0.25～0.75	N.D.～0.041
	95%ile	0.85	0.028	0.59	0.94	0.088
	Exc Frac(%)	3.98 %	0.0013 %	2.43 %	3.69 %	0.19 %
Chrome(Metal) (500 μg/m³)	Detected n/n	21/21	66/84	25/33	9/9	35/35
	AM±SD	4.01±3.05	4.50±17.52	9.89±38.0	6.35±2.33	5.68±28.92
	GM(GSD)	3.06 (2.28)	0.41 (8.27)	0.5 (10.01)	6.03 (1.39)	0.75 (3.07)
	Range	0.39～13.81	N.D.～113.57	N.D.～197.31	4.16～11.50	0.23～171.84
	95%ile	11.88	13.14	22.05	10.36	4.77
	Exc Frac(%)	_	0.038 %	0.14 %	-	-

※ n Sample number; AM, Arthmatic Mean; SD, Standard Deviation; GM, Geometric Mean; GSD, Geometric Standard Deviation; 95%ile, 95% upper value of data (calculated by GM*(GSD)^1.645); Exc Frac(%), Probability of Exceeding OEL; ND, Not Detected (conversion to 2/LOD); OEL, Occuaptional Exposure Limits

Table 5-2. Welding fume and metals concentrations by construction welding tasks_*continued*

Hazards (OEL)		Tasks				
		Pipefitter _General Building)	Pipefitter _Chemical Plant	Boilermaker	Ironwork	Metal Finishing (Metal Interior)
Copper(Fume) (100 ㎍/㎥)	Detected n/n	20/21	83/84	26/33	9/9	30/35
	AM±SD	2.57±2.75	2.69±4.84	1.16±1.08	3.58±1.79	0.29±0.27
	GM(GSD)	1.61 (3.92)	1.15 (3.48)	0.49 (6.24)	3.22 (1.62)	0.16 (3.99)
	Range	N.D.~13.38	N.D.~29.23	N.D.~4.31	1.60~6.85	N.D.~0.99
	95%ile	15.2	8.92	9.97	7.10	1.56
	Exc Frac(%)	0.13 %	0.0169 %	0.18 %	-	0.0001 %
Iron Oxide (Fume) (5 ㎎/㎥)	Detected n/n	21/21	84/84	33/33	9/9	33/35
	AM±SD	0.79±0.76	0.24±0.52	0.30±0.28	1.46±0.63	0.12±0.13
	GM(GSD)	0.44 (4.93)	0.079 (4.59)	0.19 (2.7)	1.32 (1.62)	0.045 (10.30)
	Range	0.0015~3.44	0.0009~3.64	0.028~1.21	0.64~2.19	N.D.~0.49
	95%ile	6.06	0.97	0.99	2.93	2.10
	Exc Frac(%)	6.37 %	0.33 %	0.053 %	0.30 %	2.18 %
Aluminium (Welding fume) (5 ㎎/㎥)	Detected n/n	21/21	84/84	33/33	9/9	35/35
	AM±SD	0.028±0.02	0.011±0.02	0.0093±0.0076	0.029±0.0098	0.011±0.0066
	GM(GSD)	0.021 (2.38)	0.0056 (3.12)	0.0069 (2.18)	0.027 (1.44)	0.0088 (2.40)
	Range	0.0023~0.088	0.0004~0.12	0.0019~0.029	0.015~0.042	0.0004~0.024
	95%ile	0.087	0.037	0.025	0.049	0.038
	Exc Frac(%)	-	-	-	-	-

Table 5-2. Welding fume and metals concentrations by construction welding tasks_*continued*

Hazards (OEL)		Tasks				
		Pipefitter _General Building)	Pipefitter _Chemical Plant	Boilermaker	Ironwork	Metal Finishing (Metal Interior)
Nickel (Insoluble) (500 ㎍/㎥)	Detected n/n	3/21	55/84	5/33	1/9	- /35
	AM±SD	0.21±0.52	2.33±10.53	2.33±9.39	0.10±0.25	N.D.
	GM(GSD)	0.03 (4.57)	0.17 (7.63)	0.04 (7.74)	0.03 (3.49)	N.D.
	Range	N.D.~1.91	N.D.~72.12	N.D.~47.79	N.D.~0.76	N.D.
	95%ile	0.39	4.92	1.14	0.21	-
	Exc Frac(%)	-	0.0044 %	-	-	-
Lead (50 ㎍/㎥)	Detected n/n	21/21	84/84	88/33	9/9	35/35
	AM±SD	15.57±28.76	0.38±1.03	0.42±0.85	14.82±28.44	0.90±2.84
	GM(GSD)	6.73 (4.47)	0.11 (3.02)	0.16 (3.50)	4.40 (4.34)	0.16 (4.38)
	Range	0.07~137.07	0.07~5.72	0.07~4.71	1.07~86.52	0.07~16.07
	95%ile	79.05	0.67	1.24	49.26	1.77
	Exc Frac(%)	9.04 %	-	0.0002 %	4.89 %	0.0046 %
Zinc Oxide (Fume) (5 ㎎/㎥)	Detected n/n	21/21	84/84	33/33	9/9	34/35
	AM±SD	2.01±1.88	0.14±0.28	0.038±0.038	0.011±0.0042	0.065±0.143
	GM(GSD)	1.22 (3.80)	0.057 (3.34)	0.022 (3.38)	0.0098 (1.52)	0.013 (11.33)
	Range	0.014~8.62	0.0038~1.79	0.0019~0.029	0.0047~0.016	N.D.~0.74
	95%ile	10.91	0.41	0.16	0.020	0.70
	Exc Frac(%)	14.45 %	0.010 %	0.0003 %	-	0.71 %

5.3.2 Welding fume and metal concentration level by welding technique

The concentration of welding fumes and metals were compared by different welding techniques, including SMAW, TIG welding, and CO_2 welding (Table 5-3). The concentration of welding fumes and metals by welding techniques was statistically significantly different ($p<0.05$). The GM concentration of welding fume (OEL = 5 ㎎/㎥) was the highest at 2.08 ㎎/㎥ for CO_2 welding, followed by 1.54 ㎎/㎥ for SMAW and 0.70 ㎎/㎥ for TIG welding. Compared with the welding fume concentration of TIG welding, SMAW showed 2.2 times higher, and CO_2 welding showed three times higher welding fume concentrations. The GM of manganese (OEL = 1 ㎎/㎥) concentration was highest with CO_2 welding with 0.10 ㎎/㎥, followed by SMAW with 0.011 ㎎/㎥ and TIG welding with 0.0031 ㎎/㎥. In particular, manganese concentration of TIG welding was found to be 30 times higher than that of the CO_2 welding technique, indicating the most significant difference in concentration among welding techniques. The GM of chromium (OEL = 500 ㎍/㎥) concentrations were 1.31 ㎍/㎥ and 1.27 ㎍/㎥ for CO_2 welding and SMAW, and 0.32 ㎍/㎥ for TIG welding, which was statistically significantly lower. The GM of copper (OEL = 100 ㎍/㎥) concentrations were 0.91 ㎍/㎥ for CO_2 welding, 0.82 ㎍/㎥ for TIG welding, and 0.38 ㎍/㎥ for SMAW. The GM of iron oxide (OEL = 5 ㎎/㎥) concentration was highest with CO_2 welding 0.40 ㎎/㎥, followed by SMAW 0.11 ㎎/㎥ and TIG welding 0.068 ㎎/㎥.

The GM of aluminum (OEL = 5 ㎎/㎥) concentration was highest with SMAW 0.012 ㎎/㎥, CO_2 welding 0.011 ㎎/㎥, and TIG welding 0.0056 ㎎/㎥. The GM of nickel (OEL = 500 ㎍/㎥) concentration was highest with TIG welding 0.12 ㎍/㎥, CO_2 welding 0.04 ㎍/㎥, and SMAW 0.02 ㎍/㎥. The GM of lead (OEL=50 ㎍/㎥) concentration was highest with SMAW 0.64 ㎍/㎥, CO_2 welding 0.41 ㎍/㎥, and TIG welding 0.11 ㎍/㎥. The GM of zinc oxide (OEL=5 ㎎/㎥) concentration was highest with SMAW 0.071 ㎎/㎥, TIG welding 0.034 ㎎/㎥, and CO_2 welding 0.023 ㎎/㎥.

Table 5-3. Welding fume and metals concentrations by welding techniques

Hazards (OEL)		Welding techniques			Concentration rates (as GM) A: B: C *(Kruskal-wallis-test, P value)*
		TIG Welding [A]	Shield ARC [B]	CO2 Welding [C]	
Welding Fume (5 mg/m³)	n	114	56	36	1: 2.2: 3.0
	AM±SD	1.33±2.05	3.60±7.42	2.82±2.13	
	GM(GSD)	0.70 (2.89)	1.54 (3.52)	2.08 (2.27)	
	Range	0.029～11.76	0.15～53.11	0.40～7.18	*($p<0.05$)*
	95%ile	4.03	12.19	8.01	
Manganese (Fume) (1 mg/m³)	n	114	56	36	1: 3.6: 32.4
	AM±SD	0.013±0.049	0.052±0.089	0.23±0.24	
	GM(GSD)	0.0031 (4.52)	0.011 (9.82)	0.10 (4.85)	
	Range	N.D.～0.44	N.D.～0.53	0.0021～0.75	*($p<0.05$)*
	95%ile	0.037	0.0095	1.35	
Chrome(Metal) (500 ㎍/m³)	n	114	56	36	1: 4.3: 4.3
	AM±SD	3.61±15.13	5.06±22.83	10.61±36.17	
	GM(GSD)	0.32 (8.82)	1.27 (3.39)	1.31 (7.83)	
	Range	N.D.～113.57	0.23～171.84	N.D.～197.31	*($p<0.05$)*
	95%ile	11.58	9.49	38.66	

Table 5-3. Welding fume and metals concentrations by welding techniques_*continued*

Hazards (OEL)		Welding techniques			Concentration rates (as GM) A: B: C *(Kruskal-wallis-test, P value)*
		TIG Welding [A]	Shield ARC [B]	CO2 Welding [C]	
Copper(Fume) (100 ㎍/㎥)	n	114	56	36	1: 0.5: 1.1
	AM±SD	2.31±4.27	1.15±2.01	1.88±1.64	
	GM(GSD)	0.82 (5.13)	0.38 (5.86)	0.91 (5.64)	
	Range	N.D.~29.23	N.D.~13.38	N.D.~6.85	*(p<0.05)*
	95%ile	12.08	6.98	15.65	
Iron Oxide (Fume) (5 ㎎/㎥)	n	114	56	36	1: 1.6: 5.9
	AM±SD	0.21±0.47	0.37±0.57	0.63±0.62	
	GM(GSD)	0.068 (5.18)	0.11 (10.48)	0.40 (2.71)	
	Range	N.D.~3.64	N.D.~3.44	0.053~2.19	*(p<0.05)*
	95%ile	1.02	5.07	2.05	
Aluminium (Welding fume) (5 ㎎/㎥)	n	114	56	36	1: 2.2: 2.0
	AM±SD	0.011±0.018	0.018±0.015	0.015±0.011	
	GM(GSD)	0.0056 (3.08)	0.012 (2.62)	0.0111 (2.28)	
	Range	0.0004~0.12	0.0004~0.088	0.0025~0.042	*(p<0.05)*
	95%ile	0.036	0.059	0.043	

Table 5-3. Welding fume and metals concentrations by welding techniques_*continued*

Hazards (OEL)		Welding techniques			Concentration rates (as GM) A: B: C *(Kruskal-wallis-test, P value)*
		TIG Welding [A]	Shield ARC [B]	CO2 Welding [C]	
Nickel (Insoluble) (500 ㎍/㎥)	n	114	56	36	1: 0.2: 0.4
	AM±SD	1.83±9.08	0.09±0.33	2.16±9.00	
	GM(GSD)	0.12 (7.92)	0.02 (2.62)	0.04 (7.60)	
	Range	N.D.~72.12	N.D.~1.91	N.D.~47.79	*(p<0.05)*
	95%ile	3.52	0.11	1.15	
Lead (50 ㎍/㎥)	n	114	56	36	1: 6.0: 4.0
	AM±SD	0.32±0.90	6.40±18.90	4.08±15.00	
	GM(GSD)	0.11 (2.81)	0.64 (10.53)	0.41 (6.88)	
	Range	0.07~5.72	0.07~137.07	0.07~86.52	*(p<0.05)*
	95%ile	0.58	30.8	0.0098	
Zinc Oxide (Fume) (5 ㎎/㎥)	n	114	56	36	1: 2.1: 0.7
	AM±SD	0.12±0.26	0.79±1.48	0.037±0.036	
	GM(GSD)	0.034 (6.47)	0.071 (20.81)	0.023 (2.76)	
	Range	N.D.~1.79	N.D.~8.62	0.0029~0.15	*(p<0.05)*
	95%ile	0.74	10.48	0.12	

5.3.3 Welding fume and metal concentration level by workplace characteristics

According to the characteristics of the workplace, the indoor and outdoor concentrations of welding fume and metals in general buildings pipefitters were compared (Table 5-4). The results showed that the concentration of welding fume at the underground workplace (7.75 mg/m^3) was 3.6 times higher than that at the ground-level workplace (2.15 mg/m^3) ($p<0.05$). The concentrations of manganese, iron oxide, and lead at the underground workplace (0.13 mg/m^3, 0.82 mg/m^3, 12.89 μg/m^3) were more than five times higher than those at the ground-level workplace (0.025 mg/m^3, 0.16 mg/m^3, and 2.34 μg/m^3). Also, the concentration of the zinc oxide at the underground workshop (2.10 mg/m^3) was more than four times higher than that of the ground-level workplace (0.50 mg/m^3). The concentration of chromium, aluminum, and nickel showed about twice as high as those in underground workshops, but the differences were not statistically significant.

Table 5-4. Welding fume and metals concentrations by welding workplace

Hazards (OEL)		General building pipefitting			
		Ground-level workplace [B]	Underground workplacet [A]	A/B (as GM)	*Kruskal-wallis-test, (P value)*
Welding Fume (5 ㎎/㎥)	n	8	13	3.605	p<0.05 (p=0.006)
	AM±SD	3.39±2.33	10.79±13.10		
	GM(GSD)	2.15 (3.65)	7.75 (2.08)		
	Range	0.16～6.25	2.66～53.11		
	95%ile	18.11	25.80		
Manganese (Fume) (1 ㎎/㎥)	n	8	13	5.182	p<0.05 (p=0.02)
	AM±SD	0.061±0.054	0.16±0.13		
	GM(GSD)	0.025 (7.23)	0.13 (1.93)		
	Range	0.0004～0.15	0.048～0.53		
	95%ile	0.65	0.39		
Chrome(Metal) (500 ㎍/㎥)	n	8	13	1.857	p>0.05 (p=0.128)
	AM±SD	3.63±4.35	4.24±2.08		
	GM(GSD)	2.08 (3.22)	3.88 (1.52)		
	Range	0.39～13.81	1.97～9.80		
	95%ile	14.25	7.73		

Table 5-4. Welding fume and metals concentrations by welding workplace_*continued*

Hazards (OEL)		General building pipefitting			
		Ground-level workplace B	Underground workplacet A	A/B (as GM)	*Kruskal-wallis-test, (P value)*
Copper(Fume) (100 ㎍/㎥)	n	8	13	2.667	$p>0.05$ ($p=0.111$)
	AM±SD	1.58±0.97	3.17±3.31		
	GM(GSD)	0.86 (6.88)	2.37 (2.05)		
	Range	N.D.~3.12	0.76~13.38		
	95%ile	20.41	7.71		
Iron Oxide (Fume) (5 ㎎/㎥)	n	8	13	5.156	$p<0.05$ ($p=0.036$)
	AM±SD	0.40±0.34	1.03±0.85		
	GM(GSD)	0.16 (8.51)	0.82 (1.96)		
	Range	0.0015~0.87	0.29~3.44		
	95%ile	5.39	2.48		
Aluminium (Welding fume) (5 ㎎/㎥)	n	8	13	1.693	$p>0.05$ ($p=0.515$)
	AM±SD	0.026±0.028	0.028±0.014		
	GM(GSD)	0.015 (3.50)	0.025 (1.61)		
	Range	0.0023~0.088	0.014~0.057		
	95%ile	0.118	0.056		

Table 5-4. Welding fume and metals concentrations by welding workplace_*continued*

Hazards (OEL)		General building pipefitting			
		Ground-level workplace [B]	Underground workplacet [A]	A/B (as GM)	*Kruskal-wallis-test, (P value)*
Nickel (Insoluble) (500 ㎍/㎥)	n	8	13	-	p>0.05 (p=0.154)
	AM±SD	N.D.	0.32±0.65		
	GM(GSD)	N.D.	0.05 (6.42)		
	Range	N.D.	N.D.～1.91		
	95%ile	-	1.00		
Lead (50 ㎍/㎥)	n	8	13	5.608	p<0.05 (p=0.004)
	AM±SD	4.42±3.32	22.44±35.18		
	GM(GSD)	2.34 (5.15)	12.89 (2.68)		
	Range	0.07～9.11	2.38～137.07		
	95%ile	34.72	65.25		
Zinc Oxide (Fume) (5 ㎎/㎥)	n	8	13	4.211	p<0.05 (p=0.009)
	AM±SD	0.95±0.77	2.66±2.08		
	GM(GSD)	0.50 (5.22)	2.10 (2.06)		
	Range	0.014～2.09	0.57～8.62		
	95%ile	7.56	6.88		

5.3.4 Concentration of welding fume and metal by the characteristics of welding base material

All welding work carried out at the chemical plant construction site were TIG weldings, which allowed exposure groups to be divided by the base material. The main base material can be divided into four groups: stainless steel, alloy, carbon steel, and various metals simultaneously. The GM of welding fume and metals by each group is as shown in Table 5-5. The GM of welding fume was the highest in stainless steel at 0.96 ㎎/㎥, followed by alloy at 0.96 ㎎/㎥, carbon steel at 0.67 ㎎/㎥, and mixed metal at 0.38 ㎎/㎥, but was not statistically different ($p>0.05$). Chromium, copper, iron oxide, and nickel concentration were analyzed to have statistically significant differences depending on the type of welding base material. There were no statistically significant differences in the concentration of manganese, aluminum, lead, and zinc oxide. In stainless steel welding work, the chromium and nickel concentrations were the highest, and copper and iron oxide concentration was analyzed to be the highest in alloy welding. In chemical plant construction sites, all welding work is done outdoors and applied TIG welding technique, which produces relatively little fume, so the probability of exceeding the OEL for welding fume and metal is not high as other welding techniques.

Table 5-5. Welding fume and metals concentrations by welding base material

Hazards (OEL)		Chemical plant _ welding base material				
		Stainless Steel	Alloy	Carbon Steel	Stainless Steel + Carbon Steel	*Kruskal-wallis-test, (P value)*
Welding Fume (5 mg/m³)	n	15	18	39	12	p<0.05 (p=0.021)
	AM±SD	1.84±2.62	2.03±3.08	1.23±1.92	0.42±0.17	
	GM(GSD)	0.96 (3.12)	0.96 (3.47)	0.6659 (2.73)	0.38 (1.69)	
	Range	0.096～9.1	0.11～11.76	0.097～8.02	0.13～0.70	
	95%ile	6.24	7.42	3.48	1.69	
Manganese (Fume) (1 mg/m³)	n	15	18	39	12	p>0.05 (p=0.158)
	AM±SD	0.0085±0.0094	0.03±0.10	0.0047±0.0067	0.0024±0.0022	
	GM(GSD)	0.0045 (3.52)	0.0035 (6.44)	0.0025 (3.41)	0.0014 (3.31)	
	Range	0.0003～0.031	0.0002～0.44	N.D.～0.031	0.0001～0.0080	
	95%ile	0.036	0.075	0.019	0.010	
Chrome(Metal) (500 μg/m³)	n	15	18	39	12	p<0.05 (p=0.023)
	AM±SD	15.91±38.31	1.73±2.40	2.59±7.95	0.59±0.43	
	GM(GSD)	1.19 (11.50)	0.63 (6.39)	0.22 (8.67)	0.38 (3.42)	
	Range	N.D.～113.57	N.D.～9.91	N.D.～35.78	N.D.～1.40	
	95%ile	65.9	13.4	7.84	2.87	

Table 5-5. Welding fume and metals concentrations by welding base material_*continued*

Hazards (OEL)		Chemical plant _ welding base material				
		Stainless Steel	Alloy	Carbon Steel	Stainless Steel + Carbon Steel	*Kruskal-wallis-test, (P value)*
Copper(Fume) (100 ㎍/㎥)	n	15	18	39	12	p<0.05 (p=0.041)
	AM±SD	2.10±1.66	5.13±7.28	2.34±4.71	0.89±0.64	
	GM(GSD)	1.31 (3.63)	2.18 (4.10)	0.95 (3.26)	0.69 (2.20)	
	Range	N.D.~5.18	0.25~29.23	0.14~21.82	0.16~2.36	
	95%ile	10.93	22.16	6.62	2.52	
Iron Oxide (Fume) (5 ㎎/㎥)	n	15	18	39	12	p<0.05 (p=0.008)
	AM±SD	0.1779±0.1973	0.4906±0.85	0.22±0.46	0.0449±0.05	
	GM(GSD)	0.0963 (4.00)	0.1589 (5.63)	0.077 (3.88)	0.0249 (3.80)	
	Range	0.0021~0.67	0.0052~3.64	0.0060~2.53	0.0009~0.18	
	95%ile	0.94	2.73	0.71	0.22	
Aluminium (Welding fume) (5 ㎎/㎥)	n	15	18	39	12	p>0.05 (p=0.330)
	AM±SD	0.021±0.035	0.0094±0.011	0.0100±0.018	0.0051±0.003	
	GM(GSD)	0.0086 (3.91)	0.0062 (2.38)	0.0052 (3.30)	0.0039 (2.54)	
	Range	0.0004~0.12	0.0017~0.047	0.0004~0.12	0.0004~0.011	
	95%ile	0.081	0.026	0.037	0.018	

Table 5-5. Welding fume and metals concentrations by welding base material_*continued*

Hazards (OEL)		Chemical plant _ welding base material				
		Stainless Steel	Alloy	Carbon Steel	Stainless Steel + Carbon Steel	*Kruskal-wallis-test, (P value)*
Nickel (Insoluble) (500 μg/㎥)	n	15	18	39	12	p<0.05 (p=0.027)
	AM±SD	9.65±23.84	0.77±1.15	0.87±2.48	0.31±0.27	
	GM(GSD)	0.71 (8.72)	0.18 (7.84)	0.10 (7.04)	0.19 (3.48)	
	Range	N.D.~72.12	N.D.~4.03	N.D.~10.79	N.D.~0.93	
	95%ile	25.04	5.34	2.41	1.48	
Lead (50 μg/㎥)	n	15	18	39	12	p>0.05 (p=0.958)
	AM±SD	0.34±0.95	0.26±0.65	0.27±0.68	0.95±2.05	
	GM(GSD)	0.10 (2.93)	0.11 (2.66)	0.10 (2.68)	0.15 (5.34)	
	Range	0.07~3.75	0.07~2.83	0.07~3.16	0.07~5.72	
	95%ile	0.61	0.53	0.52	2.31	
Zinc Oxide (Fume) (5 ㎎/㎥)	n	15	18	39	12	p>0.05 (p=0.193)
	AM±SD	0.19±0.33	0.091±0.15354	0.17±0.35	0.038±0.020	
	GM(GSD)	0.082 (3.64)	0.049 (2.71)	0.063 (3.93)	0.033 (1.72)	
	Range	0.0087~1.30	0.012~0.68	0.0038~1.79	0.0159~0.077	
	95%ile	0.68	0.25	0.60	0.081	

5.3.5 Comparison of within and between worker variations

The geometric standard deviation (GSD) of three samples evaluated for three consecutive days by the same welders was calculated. The median values of each individual workers three-day GSDs were used as within-worker variations. The geometric means of each worker's same task were calculated, and the mean GSDs in the same tasks were used as between worker variations.

The within-worker variations of welding fumes were largest in metal finishing workers (1.932), followed by ironworkers (1.773), chemical plants pipefitters (1.772), boilermakers (1.437), and general building pipefitters (1.151). The within-worker variations of welding fumes were inferred as influencing irregular work style and outdoor work environment. However, between worker variations were largest in general building pipefitters (3.050) followed by chemical plants pipefitters (2.634), boilermakers (2.146), metal finishing worker (1.440) and ironworkers (1.297).

Between worker variations were more extensive than within-worker variations in general building pipefitters, chemical plants pipefitters, and boilermakers. Within-worker variations were more extensive than between worker variations in ironworkers and metal finishing workers welding fumes and most of metals concentration. The determination of homogeneous exposure group and the number of repeated measurements should be decided depending on within and between worker variations.

Table 5-6. Median value of within and between worker geometric standard deviation of welding fume and metals

Task	k	N	Welding Fume	Manganese	Chrome (Metal)	Copper (Fume)	Iron Oxide (Fume)	Aluminium (Welding fume)	Nickel (Insoluble)	Lead	Zinc Oxide (Fume)
			GSD_w GSD_b	GSD_w GSD_b	GSD_w GSD_b	GSD_w GSD_b	GSD_w GSD_b	GSD_w GSD_b	GSD_w GSD_b	GSD_w GSD_b	GSD_w GSD_b
Pipefitter (General)	7	21	1.151* < 3.050	1.520* < 3.415	1.366* < 2.081	1.242 < 2.353	1.698* < 3.232	1.342* < 2.240	- / 5.692	1.387* < 4.023	1.373* < 2.777
Pipefitter (Chemical)	28	84	1.772* < 2.634	2.091* < 3.306	5.375* < 4.876	2.031* < 2.861	2.346* < 3.672	1.848* < 2.434	2.943* < 7.581	- / 3.265	2.246* < 2.614
Boiler maker	11	33	1.437* < 2.146	1.905* < 3.796	1.809* < 7.087	2.474* < 2.419	1.776* < 2.381	1.639* < 1.862	- / 9.371	1.353 < 3.264	1.731* < 3.080
Ironwork	3	9	1.773 > 1.297	1.601 > 1.250	1.138 < 1.239	1.696 > 1.130	1.700 > 1.303	1.349 > 1.212	- / 4.739	1.616 < 5.382	1.505 > 1.243
Metal Finishing	12	35	1.982 > 1.440	3.530 > 2.385	1.485 < 3.518	3.821 > 1.972	2.902 > 2.137	2.143 > 1.504	- / -	- / 4.388	3.809 > 3.511

* $p < 0.05$ (ANOVA analysis)

※ k, number of workers; N, number of samples; GSD_w, Within-worker variation; GSD_b, Between worker variation

5.4. Discussion

According to the results of the evaluation of welding fumes and metals generated by welding tasks at the construction site, the exposure to welding fume, lead, and zinc oxide was highest for general building pipefitters. The exposure concentrations of manganese, iron oxide, chromium, copper, and aluminum were the highest for ironworkers. Choi et al. (1999) compared the concentration of welding fumes by industry. They reported that the welding fume concentration in the automobile industry was 0.92 ㎎/㎥, the metal-related industry was 4.10 ㎎/㎥, and the shipbuilding industry was 5.59 ㎎/㎥. The results indicated that general building pipefitters and ironworkers at the construction sites were exposed to welding fume concentrations similar to those of shipbuilding and metal-related industry welders, and chemical plant pipefitters and metal finish welders were exposed to welding fume concentrations similar to those of automobile industry welders. In contrast to the prediction that welding fume concentrations at construction sites would be low, because it is generally performed outdoors, the concentrations were similar to those of manufacturing welding processes. In particular, in general building pipefitting work, the welding fume concentration in the underground workplace (7.75 ㎎/㎥, n = 13) was 3.6 times higher than that in the ground-level workplace (2.15 ㎎/㎥, n = 8), and the concentration of manganese (fume), iron oxide (fume), and lead was about five times higher than that in the ground-level workplace. General building pipefitting work was usually carried out at an underground workplace to prevent interference from weather conditions. However, underground workplaces have a poor ventilation environment. Therefore, It is necessary to educate employers and workers that ground-level workplace should be used, when possible.

The use of portable local exhaust ventilation is essential when welding in underground workplaces. Domestic studies were conducted on construction welding fumes by Shin (2004) and Kim et al. (2013). Shin's (2004) research evaluated galvanized pipe welding in an underground workshop and reported that zinc oxide (GM) was 3.08 ㎎/㎥, slightly higher than the level of 2.10 ㎎/㎥ found in this study. The study by Kim et al. (2013) showed a higher concentration than this study's results, with iron oxide at 6.94 ㎎/㎥, manganese at 1.04 ㎎/㎥, and zinc oxide at 0.96 ㎎/㎥. The mean concentration to which boilermakers (Flynn & Susi, 2012) were exposed was 12.36 ㎎/㎥ for welding fumes and 0.29 ㎎/㎥ for manganese, followed by ironworkers at 7.07 ㎎/㎥ for welding fumes and 0.13 ㎎/㎥ for manganese, and pipefitters at 2.89 ㎎/㎥ for welding fumes and 0.077 ㎎/㎥ for manganese. In this study, the boilermaker showed low welding fume exposure concentrations. However, in this study, welding work was not carried out inside the boiler, causing an underestimation of the concentration. Therefore, further study is required to evaluate welding work inside the boiler. The welding technique, the type of the welding base material, and the workplace characteristics (e.g., ventilation conditions) can affect the concentration of welding fumes and metals. According to the welding technique, the welding fume concentration of CO_2 welding (2.08 ㎎/㎥) and SMAW (1.54 ㎎/㎥) were not statistically different, but TIG welding (0.70 ㎎/㎥) had a statistically lower concentration. The concentration of manganese in CO_2 welding was about 32 times higher than that of TIG welding, and the concentration of iron oxide in CO_2 welding was about six times higher than that of TIG welding. However, the nickel concentration was higher in TIG welding compared to other welding techniques. CO_2 welding and SMAW mainly use carbon steel as the welding base material, and TIG welding uses mostly stainless steel and alloy. The specific welding base material according to the welding technique caused a difference in the concentration of metals. CO_2 welding has the characteristics of high current density, high penetration, and fast welding speed, so the volume of fumes generated was higher than that of other welding techniques (Lee, 2009). SMAW generates an electric arc between the flux-coated welding rod and the object to be welded and is welded by the arc heat. SMAW is the most widely used welding techniques. However, SMAW generates a large volume of welding fumes and flares. TIG welding uses arc heat generated between the tungsten electrode and the base material or weld pool without using separate welding rods. Therefore, the process generates fewer welding fumes than other techniques. However, as a limitation of this study, CO_2 welding and TIG welding were mostly performed outdoors, whereas SMAW was done indoors and outdoors. A comparative study of welding fume concentrations by welding technique (Choi et al., 1999) reported 3.84 mg/m³ for CO_2 welding, 2.23 mg/m³ for TIG welding, 2.09 mg/m³ for SMAW, 1.36 mg/m³ for submerged arc welding, and 0.15 mg/m³ for spot welding, consistent with the results of this study.

Lee et al. (1999) reported that the concentration of CO_2 in welding fume from welding with mild steel was about 4.7 times higher than that of SMAW with mild steel and 3.1 times higher than CO_2 welding with stainless steel. In Yoon's (2009) study, the CO_2 welding technique had six times higher welding fumes, 15 times higher manganese, seven times higher zinc oxide concentrations than SMAW and submerged arc welding techniques. Most effort is required to reduce the concentration of welding fume exposure from CO_2 welding techniques.

The concentration of welding fumes in the underground workplace was 3.6 times higher than that of the ground-level workplace. The concentration of manganese, iron oxide, and lead in the underground workplace was about five times higher than that of the ground-level workplace. A study by Kwag and Paik (1997) also compared the concentrations according to workplace characteristics. This study found that the welding fume concentration in the enclosed workplace was 3.2 times higher than that of the open workplace. In underground and indoor workplaces such as those of pipefitters, it is essential to reduce welding fumes using a portable local exhaust system during welding work at construction sites. In the study of Meeker et al. (2007), the concentration of welding fumes and manganese were compared according to the use of local exhaust devices in welding work in construction sites. In the experimental environment, the manganese concentration decreased by 75% (13 $\mu g/m^3$ vs. 51 $\mu g/m^3$; $p < 0.05$), and the welding fume concentration decreased by 60% (0.74 mg/m^3 vs. 1.83 mg/m^3; $p < 0.05$). At the actual worksite, the manganese concentration decreased by 53% (46 $\mu g/m^3$ vs. 97 $\mu g/m^3$; $p < 0.05$), and the welding fume concentration decreased by 10% (4.5 mg/m^3 vs. 5.0 mg/m^3; $p < 0.05$). Thus, if a portable local exhaust device is used for welding work at the construction site, it effectively reduces manganese concentrations. In particular, it has a higher effect on indoor work than outdoor work. Lee et al. (2000) reported that the fume-blocking effect by the type of welding face shield was 67.6% for the head-attached type and 58.5% for the handle type, but the fume-blocking effect for the air-supplied welding surface was very high at 99.2%. In outdoor welding work, in which it is challenging to install portable local exhaust devices, the use of a supply fan is necessary to prevent welding fumes from remaining in the worker's breathing zone. It is also known that wearing both a welding face shield and mask for fumes at the same time has a more significant effect on fume blocking than wearing either the welding face shield or the mask alone. In a study by Jeong (2002), the exposure concentration of welding fumes and metals was compared according to the distance from the welding surface to the arc. The study found that the exposure concentration was especially higher at distances of less than 40 cm. As for the characteristics of the metals generated by the welding base material, chromium and nickel concentrations were the highest in stainless steel welding work, and copper and iron oxide concentrations were the highest in alloy welding work. However, the exposure concentration to chromium and nickel was very low, at less than 10% of the OEL, because outdoor work and TIG welding techniques were applied in the study. When using the TIG welding technique, tungsten is used as an electrode, and no separate welding rod is consumed. However, since chromium and nickel are suspected of being highly harmful metals, continuous monitoring is required, depending upon the specific working environments. Kim and Kim's (2012) study emphasized that the proportion of nanoparticles in welding fumes was 58%, which is equivalent to nanomaterials defined by the European Union (more than 50%, nanoparticles), and further study on the distribution of the particles in welding work is required.

5.5. Conclusions

Construction welders were found to be at risk of exposure to welding hazard levels exceeding the OEL. In particular, welding high-risk tasks like those performed by general building pipefitters and ironworkers, as well as underground welding work and CO_2 welding need special occupational health management plans including the use of air supply and exhaust equipment, safety and health education, and dust masks for fumes. In addition, there is a need to establish construction-specific work monitoring systems, health planning, and management practices.

6. Exposure Assessment of Asphalt Fumes and Polycyclic Aromatic Hydrocarbon among Road Pavers[5)]

6.1. Introduction

Asphalt is a dark brown to black solid ingredient that ultimately results from the refining process of crude oil and consists of thousands of high molecular hydrocarbons (Lee SB et al., 2012). Generally called asphalt in the United States and bitumen in Britain, the material is mainly used for road pavement and roof waterproofing. To use asphalt for road paving, thick aggregates (such as gravel, etc.), fine aggregate (such as sand, etc.), and pavement filler (such as stone powder, etc.) are mixed with asphalt to produce asphalt concrete (so-called ascon) and heated to high temperatures.

The asphalt pavement operation involves pouring ascon carried by a dump truck onto a paver finisher and applying the ascon at a certain thickness by the paver finisher. Road pavers follow the vehicle to level the ascon. Afterward, the first compression is carried out by a macadam roller vehicle (iron wheeled), which passes over the paved road, and the second compression is carried out by a tire roller vehicle (rubber-wheeled). Since ascon cannot be stored, it is produced and supplied directly by nearby ascon manufacturers in the amount required at the paving site. Produced ascon should be stored at a high temperature of about 160℃ or higher until it arrives at the site. Workers are exposed to asphalt fumes and PAHs contained in

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ascon in the process of laying and compressing the hot ascon to a certain thickness.

The International Agency for Research on Cancer (IARCs) reported that the evidence for an association between the carcinogenicity of asphalt fumes and workers exposed by road pavement work is not yet sufficient. However, in ongoing research reports related to carcinogenicity, asphalt fumes have been designated group 2B possible carcinogens (IARC Monographs, 2013). As for the non-carcinogenicity health risks associated with asphalt fumes, acute health effects such as skin and eye irritation, nausea, abdominal pain, headache, and fatigue twere reported through a questionnaire survey of workers handling asphalt at construction sites (Butler et al., 2001). Studies have shown that workers exposed to asphalt fumes had a higher incidence of sore throat and eye, nose, and throat irritation than non-exposed workers (Tepper AL, 2006).

PAHs are the primary cause of the cancer risk from exposure to asphalt fumes. PAHs are aromatic hydrocarbons with two or more benzene rings, produced in refining crude oil, the raw material of asphalt, at high temperatures. PAHs are known to be highly persistent, bio-accumulative, carcinogenic, and mutagenic and have reproductive effects. PAHs are particularly known to cause skin cancer, lung cancer, bladder cancer, kidney cancer, and breast cancer. Recent studies using animal testing showed that exposure to PAHs in asphalt fumes increased oxidative stress and caused reproductive mutations in DNA (Bal et al., 2018).

The exposure concentration of PAHs in domestic asphalt road pavement work has not been studied. This chapter evaluated the exposure concentration of asphalt fumes and PAHs during asphalt road pavement work and prepared a work environment management plan accordingly.

6.2. Materials and methods

6.2.1 Exposure group selection and task description

Asphalt fume and PAHs concentrations were evaluated between June and July 2017 for one industrial complex and two national road construction sites with applied asphalt road pavement (Table 6-1). Measurements were carried out for two consecutive days for each measurement location. Pavement work was carried out continuously for more than 8 hours a day. The measurement was performed for more than 6 hours a day and evaluated as a time-weighted average concentration for 8 hours. In this study, target research groups were road pavers(n=24), paver finisher operators(n=6), macadam roller operators (n=8), and tire roller operators (n=4).

Table 6-1. Target Monitoring Workplace

Site	A	B	C
Location(City)	Gimhae	Busan	Yangsan
Road type	Road in Industrial complex	Natioanl road	Natioanl road
Function of road	General Road	Bridge	General Road
Asphalt type	General Ascon	General Ascon	General Ascon
Pavement	Middle-Layer Pavement	Middle-Layer Pavement	Top-Layer Pavement
Paving tickness	19 mm	10 mm	19 mm
Sampling period	June, 2017	June, 2017	June, 2017
Sampling time(mean)	100 ~ 460 min (385.2 min)	142 ~ 401 min (331.5 min)	125 ~ 480 min (409.7 min)
No of sample	16	16	16

6.2.2 Sampling and analysis

Asphalt fumes as benzene soluble

Asphalt fumes (benzene soluble) were sampled and analyzed by the NIOSH Manual of Analytical Methods(NMAM) #5042 (NIOSH, 2003). A 37-mm PTFE filter (2-μm pore size, SKC, USA) was mounted on a 3-piece cassette and collected at a flow rate of about 2 L/min using a pump (Escort Elf Sampling Pump; MSA, USA). The on-site and laboratory blank filters were analyzed for correction. The pumps were pre-and post-calibrated using a calibrator (Dry cal, Defender 520-M, MesaLabs, USA). The weight of a PTFE filter (37 mm, 2 μm pore size, SKC, USA) pre-and post-sample collection was weighed on an electronic balance (Mettler Toledo, XP2U, Switzerland, readability: 0.1 μg) to evaluate the gravimetric analysis of dust. After weighing the total dust, the PTFE filter was placed in a 15 ml test tube, 3 ml of benzene was added, and extracted for 20 minutes with an ultrasonic generator (sonicator, Branson 8510, USA). The benzene extract (2 ml) was aliquoted using a glass pipet and then filtered using a syringe (hydrophobic PTFE, Millipore). The filtered liquid was placed in a weighing dish weighed in advance, dried in a vacuum oven (OV-12, JEIO TECH, Korea) for about 2 hours, and then weighed again. The concentration was calculated from the weight remaining after the benzene volatilized. The temperature and pressure of the oven were set at 40℃, 50 ~ 200 ㎜Hg. The detection limit of asphalt fume was 0.0357 ㎎/sample, which was three times the standard deviation of the blank samples.

Polycyclic aromatic hydrocarbons

PAHs were sampled and analyzed by the NIOSH Manual of Analytical Methods(NMAM) #5506 (NIOSH, 2003). A 37-㎜, 2-㎛ PTFE filter and washed XAD-2 (100 ㎎/50 ㎎, ORBO 43, Supelco) were connected and collected at a flow rate of about 2 L/min using a pump(Escort Elf Sampling Pump; MSA, USA). Samples were wrapped in aluminum foil during and after collection to avoid exposure to sunlight (heat and ultraviolet rays), and stored in a refrigerator for transportation. Immediately after transportation to the laboratory, it was pretreated and stored at 0°C or below. The on-site and laboratory blank samples were analyzed for correction. The pumps were pre-and post-calibrated using a calibrator (Dry cal, Defender 520-M, MesaLabs, USA). After sample collection, the PTFE filter and the washed XAD-2 were transferred to a test tube (15 ml high-clarity polypropylene conical tube), and 5 ml of acetonitrile was injected, and the lid was closed and sonicated for 30 to 60 minutes. The extracted sample was filtered using a 0.45 µm syringe filter and analyzed using a liquid chromatograph (waters acquity UPLC H-Class, USA)-fluorescence detector (350 nm/397 nm). Acenaphthene, Phenanthrene, Anthracene, Fluoranthene, Pyrene, Benz(a)anthracene, Chrysene, Benzo(b)fluoranthene, Benzo(k)fluoranthene, Benzo(a)pyrene, Fluorene, Acenaphthylene, Debenz(a,h) anthracene, Benzo(ghi)perylene and indeno(1,2,3-C,D) pyrene were evaluated. Among the sub-compounds of PAHs, benzo(a)pyrene, known to have the highest toxicity, is used as a toxicity value of 1. Benzo(a)pyrene Equivalent Factors (BaPeq) is calculated to multiply the Toxic Equivalent Factors (TEF) and the AM concentration of each sub-compounds of PAHs.

6.2.3 Statistical analysis

The results were tested for normality to examine the characteristics of distribution using the Shapiro-Wilk test. Depending on the evaluation groups, evaluation groups did not follow the normal distribution or the log-normal distribution, so both arithmetic mean (AM) and geometric mean (GM) were summarized. ANOVA, T-test, and non-parametric test were performed to compare averages by job type. PASW version 18.0 was used for statistical analysis.

6.3. Results

6.3.1 Asphalt fume concentration as benzene soluble

The concentration of asphalt fume (benzene soluble) measured at three construction sites was summarized by job type. The GM of 42.32 ㎍/㎥ (ND ~ 308.71 ㎍/㎥) was the highest in the road pavers, followed by paver finisher operators, 41.57 ㎍/㎥ (ND ~ 259.01 ㎍/㎥), macadam roller operators 31.9 ㎍/㎥ (ND ~ 171.55 ㎍/㎥), tire roller operators 30.31 ㎍/㎥ (ND ~ 72.13 ㎍/㎥) (Table 2). In the concentration of asphalt fume (in total dust) by job type, the GM of 212.95 ㎍/㎥ (78.38 ~ 691.43 ㎍/㎥) was the highest in the road pavers, followed by paver finisher operators, 148.33 ㎍/㎥ (63.15 ~ 273.57 ㎍/㎥), tire roller operators, 140.5 ㎍/㎥ (103.71 ~ 285.11 ㎍/㎥), and macadam roller operators, 83.39 ㎍/㎥ (39.95 ~ 295.16 ㎍/㎥). Among the total dust, asphalt fumes have a log-normal distribution by job type, and asphalt fumes (benzene soluble) have a log-normal distribution only from the data of the paver finisher operators. In the case of asphalt fume (in total dust), the difference in concentration by job types was statistically significant due to ANOVA analysis (95% significance). On the other hand, in the asphalt fume (benzene soluble) concentration analyzed by the non-parametric test method, there was no difference in the concentration between occupations (Table 6-2).

Table 6-2. Concentration of asphalt fume in asphalt road pavement work

(Unit: ㎍/㎥)

Job	Classification	Asphalt Fume	
		Total	Benzene soluble aerosol
Paver operator	n	6	6
	Distribution	log-normal	log-normal
	AM±SD	164.23±75.94	76.36±92.82
	GM(GSD)	148.33(1.68)	41.57(3.66)
	Range	63.15～273.57	N.D.～259.01
road paver	n	24	24
	Distribution	log-normal	- (p=0.022)
	AM±SD	243.03±133.75	64.85±73.91
	GM(GSD)	212.95(1.70)	42.32(2.37)
	Range	78.38～691.43	N.D.～308.71
Macadam Roller Operator	n	8	8
	Distribution	log-normal	- (p=0.012)
	AM±SD	109.81±92.08	52.04±61.14
	GM(GSD)	83.39(2.16)	31.9(2.66)
	Range	39.95～295.16	N.D.～171.55
Tire Roller Operator	n	4	4
	Distribution	log-normal	- (p=0.014)
	AM±SD	154.65±87.21	35.08±24.73
	GM(GSD)	140.5(1.609)	30.31(1.79)
	Range	103.71～285.11	N.D.～72.13
Comparison of average concentration		*ANOVA test, p<0.05*	*Nonparametric Test, p=0.861*

※ AM, Arthmatic Mean; SD, Standard Deviation; GM, Geometric Mean; GSD, Geometric Standard Deviation; ND, Not Detected

6.3.2 Concentration of polycyclic aromatic hydrocarbons

The GM concentration of total PAHs exposed during asphalt paving work was the highest at 37.5 ㎍/㎥ (17.55 ~ 73.20 ㎍/㎥) in paver finisher operators, and 20.13 ㎍/㎥ (1.92 ~147.62 ㎍/㎥) for the road pavers, 8.66 ㎍/㎥ (3.66 ~ 19.70 ㎍/㎥) for the tire roller operators, and 6.29 ㎍/㎥ (2.99 ~ 18.62 ㎍/㎥) for the macadam roller operators (Table 6-3 and Figure 6-1). In the concentration of PAHs by sub-compounds of the paver finisher operators, the concentration was higher to acenaphthylene (8.45 ㎍/㎥), benz(a)anthracene (8.18 ㎍/㎥), pyrene (5.72 ㎍/㎥), fluoranthene (2.62 ㎍/㎥). Benzo(a)pyrene (0.29 ㎍/㎥) and debenz(a,h)anthracene (0.75 ㎍/㎥), which are known to have carcinogenic risk were also detected. In the concentration of PAHs by sub-compounds of the road pavers, the concentration of acenaphthylene (3.12 ㎍/㎥), benz(a)anthracene (2.60 ㎍/㎥), pyrene (2.36 ㎍/㎥), and naphthalene (1.62 ㎍/㎥) was in the order of higher concentration and benzo(a)pyrene (0.088 ㎍/㎥) and debenz(a,h)anthracene (0.40 ㎍/㎥) were detected. Benzo(a)pyrene (0.024 ㎍/㎥) was detected by the macadam roller operator, but debenz(a,h)anthracene was evaluated below the detection limit. In tire roller operators, both benzo(a)pyrene and debenz(a,h) anthracene were evaluated below the detection limit.

Table 6-3. Concentration of polycyclic aromatic hydrocarbon in asphalt road pavement work

(Unit: μg/㎥)

Job		Naphthalene	Acenaphthylene	Acenaphthene	Fluorene	Phenanthrene	Anthracene	Fluoranthene	Pyrene	Benz(a) anthracene
LOD(μg/sample)		0.409	0.291	0.128	0.112	0.020	0.004	0.026	0.063	0.006
TEF		0.001	0.001	0.001	0.001	0.001	0.01	0.001	0.001	0.1
Paver finisher operator (n=6)	AM±SD	2.73±2.54	8.99±3.16	2.13±1.12	1.05±2.39	1.17±0.61	0.16±0.08	3.69±3.48	6.30±2.99	12.66±14.12
	GM(GSD)	2.09(2.13)	8.45(1.50)	1.41(4.13)	0.15(6.13)	0.96(2.24)	0.14(1.78)	2.62(2.42)	5.72(1.62)	8.18(2.63)
	Range	0.79~7.79	4.46~12.74	0.08~3.16	0.07~5.93	0.21~1.90	0.07~0.26	1.08~9.83	3.27~10.89	3.53~39.13
	BaPeq	0.00273	0.00899	0.00213	0.00105	0.00117	0.0016	0.00369	0.006297	1.266
Road paver (n=24)	AM±SD	2.59±2.52	5.75±5.32	2.79±4.47	0.07±0	0.8±0.833	0.118±0.1	2.30±2.17	4.60±4.32	11.32±19.91
	GM(GSD)	1.62(2.904)	3.12(3.93)	0.81(6.79)	0.07(1)	0.35(4.61)	0.063(4.427)	1.16(5.043)	2.36(4.74)	2.60(14.89)
	Range	0.26~9.10	0.18~17.20	0.08~21.64	0.07~0.07	0.027~2.78	0.002~0.34	0.016~9.17	0.039~15.78	0.004~91.12
	BaPeq	0.00259	0.00575	0.00279	0.00007	0.0008	0.00118	0.00230	0.00460	1.1322
Macadam Roller Operator (n=8)	AM±SD	1.31±1.08	1.06±1.72	0.08±0	N.D.	0.21±0.17	0.025±0.026	0.93±0.80	1.90±1.34	1.30±2.37
	GM(GSD)	0.91(2.65)	0.38(3.98)	0.08(1)	N.D.	0.14(3.37)	0.011(4.944)	0.51(4.82)	1.51(2.11)	0.045(31.17)
	Range	0.26~3.11	0.18~4.77	0.08~0.08	N.D.	0.012~0.46	0.002~0.058	0.016~2.47	0.45~4.11	0.004~6.81
	BaPeq	0.00131	0.00106	0.00008	-	0.00021	0.00025	0.00093	0.00190	0.130
Tire Roller Operator (n=3)	AM±SD	0.69±0.18	N.D.	0.47±0.68	N.D.	0.34±0.35	0.05±0.018	1.58±1.09	2.57±2.19	3.41±3.01
	GM(GSD)	0.68(1.29)	N.D.	0.2(4.92)	N.D.	0.24(2.66)	0.048(1.421)	1.36(1.90)	2.03(2.31)	0.46(63.81)
	Range	0.56~0.90	N.D.	0.08~1.26	N.D.	0.13~0.74	0.035~0.07	0.84~2.83	0.98~5.07	0.004~5.74
	BaPeq	0.00069	-	0.00047	-	0.00034	0.0005	0.00158	0.00257	0.341

Table 6-3. Concentration of polycyclic aromatic hydrocarbon in asphalt road pavement work _Continued

(Unit: $\mu g/m^3$)

Job		Chrysene	Benzo(b) fluoranthene	Benzo(k) fluoranthene	Benzo(a) pyrene	Debenz(a,h) anthracene	Benzo(ghi) perylene	Indeno(1,2,3-C, D)pyrene	Total_PAHs
LOD(μg/sample)		0.048	0.016	0.040	0.015	0.423	0.367	0.052	-
TEF		0.01	0.1	0.1	1	1	0.01	0.1	-
Paver finisher operator (n=6)	AM±SD	0.47±0.48	0.67±0.405	0.35±0.28	0.36±0.23	1.03±0.86	0.38±0.36	0.18±0.24	42.3±21.56
	GM(GSD)	0.29(3.02)	0.37(6.04)	0.22(3.491)	0.29(2.15)	0.75(2.49)	0.30(1.90)	0.08(4.09)	37.5(1.72)
	Range	0.07~1.29	0.01~1.2	0.025~0.76	0.11~0.69	0.26~2.47	0.23~1.11	0.032~0.51	17.55~73.20
	BaPeq	0.0047	0.067	0.035	0.36	1.03	0.0038	0.018	2.81
Road paver (n=24)	AM±SD	0.49±0.49	0.33±0.47	0.22±0.30	0.27±0.35	0.58±0.656	0.31±0.41	0.08±0.12	32.62±34.11
	GM(GSD)	0.26(3.61)	0.07(7.56)	0.081(4.22)	0.088(6.27)	0.40(2.16)	0.25(1.59)	0.047(2.41)	20.13(2.94)
	Range	0.03~1.66	0.01~1.71	0.025~0.90	0.01~1.65	0.26~2.43	0.23~2.22	0.03~0.49	1.92~147.6
	BaPeq	0.0049	0.033	0.022	0.27	0.58	0.0031	0.008	2.07
Macadam Roller Operator (n=8)	AM±SD	0.095±0.094	0.033±0.066	0.042±0.047	0.10±0.18	N.D.	N.D.	N.D.	7.68±5.59
	GM(GSD)	0.063(2.55)	0.014(2.87)	0.032(1.92)	0.02(5.54)	N.D.	N.D.	N.D.	6.29(1.92)
	Range	0.03~0.25	0.01~0.195	0.025~0.16	0.01~0.43	N.D.	N.D.	N.D.	2.99~18.62
	BaPeq	0.00095	0.0033	0.0042	0.104	-	-	-	0.25
Tire Roller Operator (n=3)	AM±SD	0.26±0.22	0.61±1.04	N.D.	N.D.	N.D.	N.D.	N.D.	10.79±8.17
	GM(GSD)	0.21(2.224)	0.056(20.13)	N.D.	N.D.	N.D.	N.D.	N.D.	8.66(2.32)
	Range	0.11~0.52	0.01~1.81	N.D.	N.D.	N.D.	N.D.	N.D.	3.66~19.70
	BaPeq	0.0026	0.061	-	-	-	-	-	0.41

6.3.3 Benzo(a)pyrene equivalent factor(BaPeq) of polycyclic aromatic hydrocarbons (PAHs)

Benzo(a)pyrene, which is known to have the most toxic of PAHs′ sub-compounds, was converted to the degree of toxicity of the sub-compounds of other PAHs with a toxicity value of 1 to calculate the displayed toxicity equivalent coefficient (BaPeq). The degree of toxicity of the detailed compounds is naphthalene, acenaphthylene, acenaphthene, fluorene, phenanthrene, fluoranthene, pyrene: 0.001, anthracene, chrysene, benzo(ghi)perylene: 0.01, benzo(a)anthracene, benzo(b)fluoranthene, benzo(k) fluoranthene, indeno(1,2,3-C,D)pyrene was converted to 0.1, and debenzo(a,h) anthracene was converted to 1 (Zhao YJ et al., 2016). The sum of the BaPeq for each job was 2.81 $\mu g/m^3$ for paver finisher operators, 2.07 $\mu g/m^3$ for road pavers, 0.25 $\mu g/m^3$ for macadam roller operators, and 0.41 $\mu g/m^3$ for tire roller operators (Table 6-4). In BaPeq of the paver finisher operators by sub-compounds, benzo(a)anthracene (1.27 $\mu g/m^3$), debenzo(a,h) anthracene (1.03 $\mu g/m^3$), benzo(a)pyrene (0.36 $\mu g/m^3$) concentration were high and for road pavers, benzo(a) anthracene (1.13 $\mu g/m^3$), debenzo(a,h) anthracene (0.58 $\mu g/m^3$), and benzo(a)pyrene (0.27 $\mu g/m^3$) were high.

Table 6-4. Concentration of polycyclic aromatic hydrocarbon(PAHs) in various occupational environments

Occupational Environments	Process	ΣPAHs (AM. μg/㎥)	BaP (μg/㎥)	BaPeq (μg/㎥)	Country	Reference
Asphalt road pavement	Road paver	32.62	0.27	2.07	S.Korea	This study
	Paver finisher	42.3	0.36	2.81		
	Macadam Roller	7.68	0.10	0.25		
	Tire Roller	10.79	-	0.41		
Paint Manufacturing	-	17.48	0.30	0.40	S.Korea	Lee JS, 2004
Steel pipe coating	-	526.54	0.70	1.99		
Tar Manufacturing	Personal	17.09	0.003	0.034	S.Korea	Lee K, 2005
	Environmental	12.97	0.11	0.46		
Carbon black industry	packaging	1.95	0.34	0.57	Taiwan	Tsai P et al., 2001
	palletizing	1.45	0.29	0.31		
Traffic policeman	-	0.87	0.026	0.082	China, Tianjin	Hu Y et al, 2007
Highway toll station	-	0.33	0.022	0.041	China, Tianjin	Zhao Y et al., 2016
Vehicle Inspection factory	Bus line	0.11	0.0014	0.0044	China, Beijing	Li et al., 2013
	Gasoline line	0.056	0.0013	0.0033		
	Diesel line	0.20	0.0043	0.012		
Vehicle Inspection factory	-	1.88	0.007	0.017	S.Korea	Im HS et al., 2004
Waste Incineration	-	6.07	0.015	0.039		

※ AM, Arithmetic Mean; BaP, Benzo(a)pyrene; BaPeq, BaP equivalent concentration

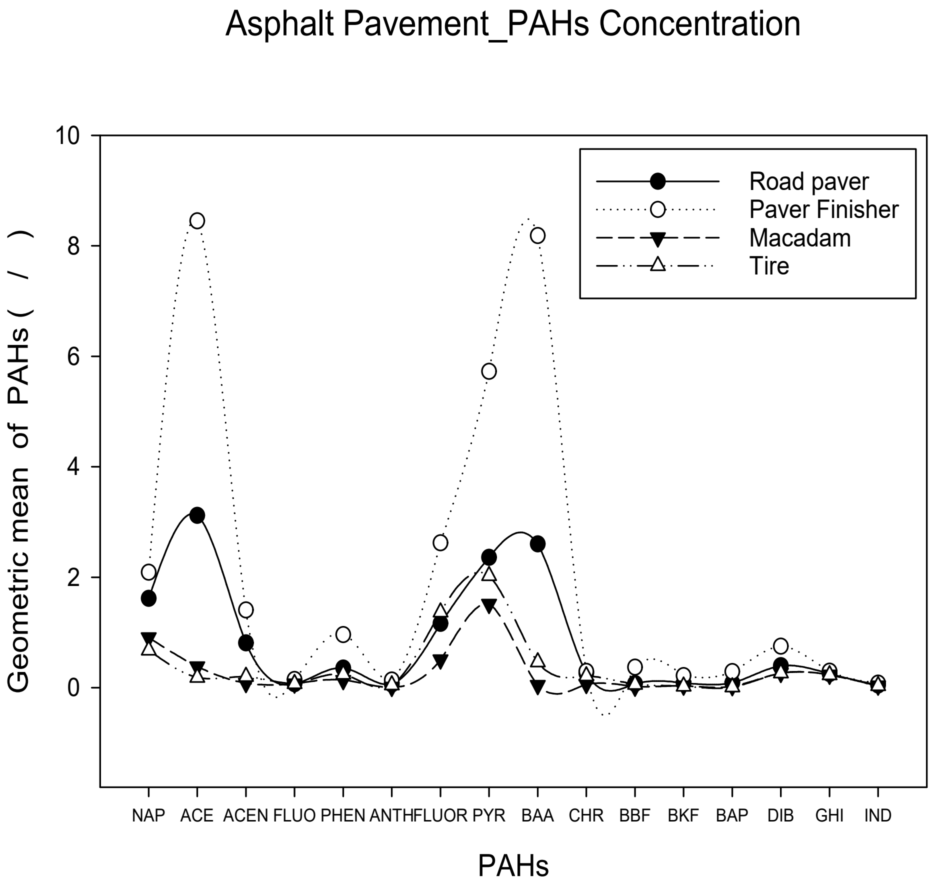

Figure 6-1. Concentration of Polycyclic Aromatic Hydrocarbon in Asphalt pavement work (GM, μg/㎥)

※ NAP, Naphthalene; ACE. Acenaphthylene; ACEN. Acenaphthene; FLUO, Fluorene; PHEN, Phenanthrene; ANTH, Anthracene; FLOUR, Fluoranthene; PYR, Pyrene; BAA, Benz(a)anthracene; CHR, Chrysene; BBF, Benzo(b)fluoanthene; BAP, Benzo(a)pyrene; DIB, Dibenz(a,h)anthracene; IND, Indeno(1,2,3-C,D)pyrene

6.4. Discussion

The concentration of asphalt fumes (benzene soluble) was investigated at three asphalt road pavement sites. The exposure concentration was highest for road pavers (42.32 ㎍/㎥), followed by paver finisher operators (41.57 ㎍/㎥), macadam roller operators (31.9 ㎍/㎥), and tire roller operators (30.31 ㎍/㎥). It was found that as the temperature of asphalt concrete (ascon) decreased over time, the exposure concentration of asphalt fumes in the air also reduced. The GM concentration of asphalt fumes was very low, at about 10% of the level of the OEL at 500 ㎍/㎥, but the GSD was 1.79 ~ 3.66, which means the distribution of asphalt fume concentrations was wide. Therefore, the estimated 95% upper concentration of asphalt fumes based on the log-normal distribution was 350.97 ㎍/㎥ for paver finisher operators, which is about 50% of the OEL.

Jeong et al. (2006) reported the concentration of asphalt fumes at one road pavement site, and the exposure concentrations of three asphalt road pavers were 410 ㎍/㎥, 290 ㎍/㎥, and 210 ㎍/㎥, followed by the paver finisher operator (180 ㎍/㎥), macadam roller operator (130 ㎍/㎥), and the tire operator, whose exposure concentration was less than the detection limit (30 ㎍/㎥). The results of a study by Jeong et al.(2006) were about ten times higher than that of this study. The reason for the difference in concentration could be estimated as follows. Previously, ascon-containing hoppers were not equipped with a ventilation system, but recently manufactured paver finisher have a ventilation system. Besides, exposure concentrations can be affected by natural ventilation from nearby buildings. The study by Jeong et al., (2006) was evaluated a road inside the city and this study was done in a national construction site outside the city.

The National Institute on Occupational Safety and Health (NIOSH) conducted an asphalt fume (benzene soluble) exposure assessment for asphalt road pavement work carried out in California in the United States from 1994 to 1997 (Butler et al, 2001). The research reported that the concentration of asphalt fumes to which paver operators was exposed 82 ~ 590 ㎍/㎥, 30 ~ 22 ㎍/㎥ for roller operators, and 55 ~ 170 ㎍/㎥ for laborers, similar to the exposure concentrations in this study.

In the case of asphalt fume concentration in total dust (before analyzing the benzene soluble concentration), the GM of 212.95 ㎍/㎥ (78.38 ~ 691.43 ㎍/㎥) was the highest for road pavers, followed by paver finishers 148.33 ㎍/㎥ (63.15 ~ 273.57 ㎍/㎥), tire roller operators 140.5 ㎍/㎥ (103.71 ~ 285.11 ㎍/㎥), and macadam roller operators 83.39 ㎍/㎥ (39.95 ~ 295.16 ㎍/㎥). Jeong et al. (2006) reported that the asphalt fume concentration in total dust was 150 ~ 170 ㎍/㎥ at the asphalt production facility, 770 ~ 860 ㎍/㎥ at the ascon manufacturing facility, and 1,010 ㎍/㎥ at the road pavement site.

Choi et al. (2000) studied asphalt fume concentrations (total dust) in parking lots at government offices and reported that the concentration of asphalt fumes to which paver finisher assistants were exposed was 7,970 ㎍/㎥, 3,430 ㎍/㎥ for paver finisher operators, 370 ㎍/㎥ for road pavers, 450 ㎍/㎥ for tire roller operators and 360 ㎍/㎥ for the tandem roller operators, and the GM of all 15 samples was 940 ㎍/㎥.

Tepper et al. (2006) reported an asphalt fume concentration exposure (total dust) of 180 ~ 220 ㎍/㎥ for paver operators, 200 ㎍/

㎥ for road pavers, and 70 ㎍/㎥ for roller operators, which were similar to the results of this study. In the study by Chung et al. (2018), the asphalt fume concentration in 12 asphalt road pavement sites in Shanghai and Hong Kong, showed a wide range of exposure concentration to paver finishers, which ranged from 167 to 7,801 ㎍/㎥ with a mean of 1,361 ㎍/㎥, followed by road pavers at 514 ㎍/㎥ (157 ~ 3,908 ㎍/㎥) and roller operators at 133 ㎍/㎥ (47 ~ 300 ㎍/㎥). Thus, the concentration of asphalt fumes varied greatly depending upon the characteristics and location of the workplace, the wind speed at the measurement date, the weather, and the type of asphalt. The exposure concentration by work type was the highest for the paver finisher operator, followed by the road paver, and those performing roller work.

The GM concentration of total PAHs exposure from asphalt paving was the highest for paver finishers, but there was considerable variation in the road pavers' exposure. The GSD of each job was the largest at 2.94 for the road pavers and the smallest at 1.72 for the paver finisher operators.

The evaluation of exposure to 16 PAHs sub-compounds during asphalt road paving work found that the concentration of pyrene, benz(a)anthracene, fluoranthene, naphthalene, acenaphthylene, and acenaphthene was higher than that of other PAHs. A study by Hicks et al. (1995) conducted an exposure evaluation of road pavers to PAHs (n = 9). Among the sub-compounds of PAHs, naphthalene (5.4 ㎍/㎥), acenaphthene (1.3 ㎍/㎥), and acenaphthylene (0.69 ㎍/㎥), fluorene (0.51 ㎍/㎥), phenanthrene (0.43 ㎍/㎥), fluoranthene (0.24 ㎍/㎥), pyrene (0.17 ㎍/㎥), benzo(e)pyrene (0.16 ㎍/㎥), chrysene (0.13 ㎍/㎥) and anthracene (0.05 ㎍/㎥) were detected.

Total PAHs were evaluated in the paint manufacturing industry and steel pipe coating industry (Lee et al., 2004), and tar production operation in the chemical product manufacturing industry (Lee et al., 2005). The GM was 17.5 ㎍/㎥ (2.6 ~ 148.4 ㎍/㎥) in the paint manufacturing facility, 526.55 ㎍/㎥ (112.1 ~ 6,311.3 ㎍/㎥) in the steel pipe coating facility, and 10.631 ㎍/㎥ (GSD 2.16) in the tar production operation in the chemical product manufacturing facility. The total PAHs exposure from tar production and in the paint manufacturing facility was similar to or somewhat higher than that of paver finishers and road pavers during asphalt road pavement work. However, the PAHs toxicity equivalent coefficient (BaPeq) for asphalt paver finishers and road pavers was 2.813 ㎍/㎥ and 2.071 ㎍/㎥, respectively, and the BaPeq from asphalt road pavement work was much higher than that found in the steel pipe coating facility (1.985 ㎍/㎥), tar production (0.46 ㎍/㎥), and paint manufacturing facility (0.394 ㎍/㎥). This result was due to the relatively high concentration of benzo(a)pyrene, benzo(a)anthracene and dibenzo(a,h) anthracene, which are highly toxic materials. Therefore, an assessment of carcinogenic effect on asphalt road pavers is needed in the future. The AM and SD of the total PAHs evaluated by domestic automobile exhaust inspectors were 1.88 ㎍/㎥ and 1.66 ㎍/㎥, respectively (Im et al., 2004), while data generated by the automobile inspection office in Beijing, China showed an AM of 0.056 ㎍/㎥ (SD 0.018 ㎍/㎥) from gasoline engine vehicle, 0.11 ㎍/㎥ (SD 0.041 ㎍/㎥) from a bus, and 0.20 ㎍/㎥ (SD 0.11 ㎍/㎥) from diesel vehicle (Li et al., 2013). Thus, the asphalt road pavement workers are exposed to PAHs concentrations about ten times higher than those at automobile inspection stations. The PAHs concentration in the general atmosphere (Chen et al., 2016) was 0.087 ㎍/㎥ in Xian, China, 0.026 ㎍/㎥ in Seoul, Korea, 0.002 ~ 0.006 ㎍/㎥ in Atlanta, GA, USA, and

0.002 ~ 0.005 $\mu g/m^3$ in Taiwan and Japan. Of the 16 PAHs sub-compounds, the KOEL and ACGIH TLVs for naphthalene are set at 10 ppm, and for some substances (phenanthrene, anthracene, pyrene, benzo(a) pyrene), the OEL is 0.2 mg/m^3. The PAHs concentrations in this study were less than 10% of the OEL, but about 400 times higher than the atmospheric concentrations (based on the air environment in Seoul).

6.5. Conclusions

The concentrations of asphalt fume and PAHs did not exceed the OEL during asphalt road paving, but, the PAHs concentrations were hundreds of times higher than the atmospheric concentrations. Also, the BaPeq values for asphalt road paving workers were higher than those of workers in other occupations exposed to PAHS even though at lower total PAHs concentrations. This study confirmed the carcinogenic hazards for asphalt road paving workers. In addition, during asphalt paving, the concentration changes could be very substantial depending upon environmental variables such as asphalt temperature, the installation of hopper ventilation systems in the paver finisher, and the surrounding building conditions. Therefore, further exposure assessment studies are required for various work sites.

7. Summary of conclusions

7.1. Summary

This study was aimed at (a) identifying the exposure hazards of construction workers, (b) conducting an exposure assessment of hazardous substances for high-risk construction workers (underground excavation workers, concrete finishers, waterproof painters, welders, and asphalt road pavers), who have a risk of exposure to carcinogenic substances such as silica, diesel engine exhausts, polycyclic aromatic hydrocarbons, solvent, welding fume, and asphalt fume and (c) determining variables most affecting hazardous material concentrations and work environment improvement methods for construction workers.

Identification of the exposure hazards among construction workers by job types

The exposure hazards of 27 construction jobs were identified and summarized. Construction workers were exposed to noise, vibrations, ultraviolet rays, solar radiation, various types of dust (cement, concrete, wood, glass wool, mineral, and gypsum), and chemicals such as crystalline silica, diesel engine exhaust, asphalt fumes, asbestos, lead, chromium, epoxy/urethane, isocyanate, carbon monoxide, metal fumes, and volatile organic compounds. The most frequently exposed seven hazards were noise, vibrations, solar radiation, crystalline silica, cement/concrete dust, metal fumes and volatile organic compounds. As for the exposure characteristics, construction workers were exposed to various hazards simultaneously, including carcinogenic substances and those with adverse reproductive effects. Construction workers have a higher incidence of cancer, respiratory diseases, musculoskeletal disorders, skin tumors, and contact dermatitis compared to general industry workers. Approved occupational disease occurred most in excavation workers (including rock blasting), general laborers, divers, concrete finishers, welders, demolition workers, stonemasons, painters, insulation workers, etc. In literature reporting lung cancers, carpenters, bricklayers, plasterers, rebar workers, stonemasons, painters, pipefitters, insulation workers, welders and electricians were most reported. Among construction workers, the job types with the highest risk of exposure to carcinogens, and which occupational cancer has been reported, were excavation workers, concrete finishers, painters, welders, and asphalt road pavers.

Exposure of high-risk construction workers to hazardous substances

In the exposure assessment of five high-risk construction workers (Table 7-1), concrete finishers (grinding work) had the highest OEL-exceeding concentrations fraction for RD (3 mg/m^3) and RCS (0.05 mg/m^3) among all job types. Of the samples, 99.6% of the RD measurements and 99.9% of RCS measurements exceeded the OEL. The estimated percentage of respirable EC (20 $\mu g/m^3$) and RCS (0.05 mg/m^3) fractions exceeding the OEL outside the excavator was 65.3% and 81.4%, respectively. In the exposure assessment of construction painters to TVOCs, 71.2% and 61.4% of the exposures from urethane painting work in bathrooms and swimming pools, respectively, exceeded the OEL (EI =1) followed by exposure on the pilot floor (37.9%), ground floor (34.4%), and rooftop (29.9%). In the exposure of construction welders to welding fumes, general building pipefitters showed the highest estimated OEL (5 ㎎/㎥) exceeding fraction as 48.2%, followed by ironworkers (31.8%), boilermakers (6.79%), chemical plant pipefitters (3.29%) and metal finishing welders (0.55%). The exposure of road pavers to asphalt fumes did not exceed the exposure limits. From the exposure assessment of construction workers, excavation workers (respirable EC and RCS), concrete finishers (RD and RCS), construction painters (TVOCs), and welders (welding fume for pipefitters, boilermakers, and ironworkers) had at least a 5% possibility of exposures exceed the exposure limits. In this study, Bayesian decision analysis was applied to determine the exposure control rates of the evaluation groups from the limited number of measurements. Categories were adopted from the AIHA Exposure Category System as (0) negligible or trivial exposure ($X_{0.95}$ < 1% OEL), (1) highly controlled ($X_{0.95}$ < 10% OEL), (2) well-controlled ($X_{0.95}$ < 50% OEL), (3) controlled ($X_{0.95}$ < 100% OEL), and (4) poorly controlled ($X_{0.95}$ > 100% OEL) (Hewett et al., 2006).

By Bayesian decision analysis, the exposure profiles for respirable EC and RCS for excavation workers outside the excavator, RD and RCS for concrete finishers (chipping and grinding), TVOCs for all construction painters, and welding fumes for general pipefitters and ironworkers showd a 100% probability for Category 4, indicating 'poorly controlled work environments'.

The variability of hazard exposure concentrations among construction workers

The characteristics of exposure assessment in the construction industry demonstrated wide concentration variations due to the mobile and varied tasks. The tasks of jobs with the highest GSD were concrete chipping, grinding and plastering performed by concrete finishers with 4.13, 3.23, and 2.86 at RCS concentrations and 3.26, 2.84, and 2.87 at RD concentrations, respectively. Excavation workers (respirable EC), general building pipefitters (welding fumes), and road pavers (asphalt fume) showed high GSD results with 3.62, 3.15, and 3.66, respectively. The groups with high GSDs should be divided into detailed homogeneous exposure groups. The high GSD indicates the probability of much higher concentrations at unmeasured construction sites (Table 7-2). However, since variability by job type was found at various worksites, it was necessary to review the day-to-day variations at each worksite. In the exposure of excavation workers at four worksites to respirable EC, except for one worksite, the day-to-day variability of respirable EC concentrations showed a GSD of less than 2, while the between company variability of the outdoor excavator had a GSD of more than 3. In the exposure of concrete finishers to RCS concentrations, 70% of the worksites showed a day-to-day GSD variability of more than 2. In the exposure of painters to TVOCs, welding fumes of the welders and asphalt fumes of the road pavers, 50% of the worksites showed a day-to-day GSD variability of more than 2. A GSD of 2.0 or higher shows relatively high fluctuation based on general gas, vapor, and particulate data analyses (NIOSH, 1975). A large GSD could underestimate the GM results (Mulhausen & Damiano, 1998). Therefore, it is necessary to apply weights for variability when evaluating work environment monitoring results for construction workers. Liedel's reporter that when the GSD of the daily concentration was about 1.22, workers should be managed to maintain less than 50% of the exposure limits not to exceed the exposure limits on days less than 5% in the 95% confidence interval. When the GSD reaches 2.0, the concentration should be less than 10% (NIOSH, 1975, 1977; Appendix Ⅵ). In addition, this variability should be applied to an appropriate sample number, homogeneous exposure groups and the estimated upper limit of concentration for risk assessment.

According to the welding fume concentration exposed to construction welders evaluated in the same workers for three consecutive days, the between-worker variations were larger than the within-worker variations in general building pipefitters, chemical plants pipefitters and boilermakers. However, the within-worker variations were larger than the between-worker variations in ironworkers and metal finishing workers. Thus, the within and between-worker variations in a homogeneous exposure group and the number of repeated measurements should be assessed.

The most influential variables and work environment improvement method for construction workers

Although there were some limitations in comparing the concentrations by exposure groups due to each specific environmental variable and variance, the main work environment improvement method suggestions follows.

- For excavation workers, the most influential variables were the ground type (rock ground) and ventilation condition (enclosed environment). Effort is needed to introduce water-spraying facilities at rocky ground excavation sites, open up the enclosed workplace as much as possible and supply fresh air and ventilation. Furthermore, the replacement of old vehicles, regular vehicles maintenance and the use of low sulfur oil is suggested.
- For concrete finishers, concrete grinding tasks in the narrow workplace have priority for improving the work environment. To protect concrete finishing workers' health, dust-minimizing

construction methods and the use of local exhaust ventilation system (grinder dust shroud collector) or water-spraying facilities targeting on fine-dust (less than 10 ㎛), simultaneously with the application of high-efficiency respirators.

· For construction painters, primer painting tasks in indoor workplaces have priority for improving the work environment. Construction painters needed to be protected from chemical agents by substituting paints with less toxic substances and using personal protective devices with appropriate protection and ventilation system.

· For construction welders, high-risk welding tasks by general building pipefitters and ironworkers, underground welding work and CO_2 welding techniques require more attention to occupational health management including use of air supply and exhaust systems, and worker training on welding fume characteristics by welding base material and welding methods.

· For asphalt road pavers, the carcinogenic exposure hazards were confirmed even though the concentration was lower compared to the exposure limits.

7.2. Conclusions and Implications

This study identified hazardous substance exposure among construction workers. Construction workers were exposed to various hazards simultaneously. The exposure assessment of construction workers demonstrated that excavation workers (respirable EC and RCS), concrete finishers (RD and RCS), construction painters (TVOCs), and welders (welding fume for pipefitters, boilermakers, ironworkers) had possibilities of at least more than 5% of the exposure evaluation samples exceeded the exposure limits and their work environment was evaluated as ‘poorly controlled’. Efforts are needed to eliminate hazards during design, substitute with less toxic materials and processes, remove workers from hazardous work, select appropriate equipment, reduce the time exposed to hazards, wear protective equipment and conduct regular health checks and concentration monitoring. The characteristics of the exposure in the construction industry showed large day-to-day variations due to the mobile and varied tasks. Therefore, in the future, it is necessary to apply weights for variability when evaluating the work environment monitoring results for construction workers and manage the hazard concentrations within the exposure limits. These variations should be applied to the decisions regarding the appropriate sample number, homogeneous exposure groups and the estimated upper limit of concentrations for risk assessment.

This research data can be used to estimate the hazards exposure levels of construction workers when adjudicating occupational disease in health compensation insurance claims, and can contribute to improving the work environment at construction sites.

7.3. Suggestions and limitations

Suggestion: Improvement in work monitoring regulations for the construction industry

The current regulations on work environment monitoring in South Korea were enacted mainly based on the manufacturing industry sector. The work monitoring cycle and evaluation targets are not appropriate for application to the construction industry. Based on this study, improvements in construction-specific work monitoring regulations are proposed as follows.

First, the current work environment monitoring cycle shall be conducted every six months and the evaluation target shall be determined by the workplace unit. However, this is not suitable for construction sites where the work environment changes frequently. Therefore, the evaluation targets may be modified according to the task for each job type and the hazard exposure levels should be continuously monitored whenever the task content changes. To this end, a principle of defining the tasks for evaluation is necessary and guidelines should be prepared to standardize the tasks by job type. The results of this study suggest that tasks can be classified into (1) jobs by processes during construction periods, (2) detailed sub-jobs or activities recommended by the construction worker's retirement credit association, and (3) detailed sub-jobs or activities further divided by work environment (including workplace volume, ventilation configuration, air-flow, and mixing characteristics), contamination sources, and the use of tools. These classifications should be re-established for each type of construction process due to the characteristics of different construction sites.

Second, the current work monitoring system has used full-shift sampling for exposure assessment, but since the daily working hours of construction workers are so different, they can be overestimated or underestimated depending upon the degree of work hours on the evaluation day. Therefore, the full-shift sampling method may be modified to a task-based sampling method, and the concentration can be calculated by the actual working hours. Task-based sampling has been recommended for highly mobile, complex and variable jobs such as thoes of construction workers (Neitzel et al., 1999; Kerr et al., 2002; Seixas et al., 2005; Virji et al., 2009).

Third, the definition of a task remains a critical aspect of a task-based strategy, and the lack of consistency in task definition makes it difficult to compare results (Virji et al., 2009). Since it is important to understand the variability of exposure in tasks, it is proposed the task records should contain both field researcher observations and construction worker's report.

Limitations

This study did not observe seasonal changes in concentrations. Among evaluated hazards, dust concentrations may vary due to seasonal changes in humidity and ventilation conditions. For painters, some polar chemical including methanol, ethanol and methyl acetate was not included in this study as active sampling methods could not be used. This might be a limitation of this study. So there were underestimations of EI values. On the other hand, as we did not calculate TWA for each task, there might be some overestimations for workers' exposure levels. When someone wants to use the data for any epidemiological study or compare to other monitoring results care should be taken by introducing time adjustment to real working time with hazardous substances for each task with task-time analysis. In Bayesian decision analysis, some workers were measured repeatedly for consecutive 2 ~ 3 days, but when performing the analysis, all data were considered individually measured and evaluated. Also a small number of samples for the tasks might be another weakness. Additional monitoring studies with copious sample numbers should be followed to fortify risk-based analysis and management for construction workers.

Table 7-1. Bayesian decision analysis probability(%) and exposure risk of exceeding the OEL by construction job type

Job	Task	Hazards	n	GM	GSD	Min	Max	Exc. Frac (%)	Estimated Exc. Frac(%) (95%LCL-UCL)	Estimated 95%ile conc. ($X_{0.95}$) (95%LCL-UCL)	Bayesian decision Analysis* Exposure Rating (posterior) Decision probability (%) ($X_{0.95}$) Category** (1)	(2)	(3)	(4)
Excavation workers	Inside excavator	Respirable EC(㎍/㎥)	23	8.69	2.42	1.57	58.4	13.0	17.3 (8.9 ~ 30.2)	37.3 (25.2 ~ 68.3)	0	0	0.2	99.9
		RCS(㎎/㎥)	6	0.016	1.97	0.006	0.035	0	4.99 (0.4 ~ 29.8)	0.05 (0.03 ~ 0.20)	0	0.9	37.1	62.2
	Outside excavator	Respirable EC(㎍/㎥)	30	33.20	3.61	3.15	191	70.0	65.3 (53.1 ~ 75.9)	275.56 (165 ~ 576)	0	0	0	100
		RCS(㎎/㎥)	11	0.08	1.61	0.04	0.15	70.0	81.4 (61.1 ~ 92.8)	0.174 (0.13 ~ 0.31)	0	0	0	100
Concrete finisher	Chipping	RD(㎎/㎥)	36	1.78	3.26	0.19	62.7	27.7	32.9 (23.4 ~ 44)	12.4 (8.08 ~ 22.8)	0	0	0	100
		RCS(㎎/㎥)	36	0.12	4.13	0.005	3.06	75	73.7 (62.9 ~ 82.5)	1.27 (0.76 ~ 2.64)	0	0	0	100
	Grinding	RD (㎎/㎥)	58	49.96	2.84	4.26	368	100	99.6 (98.7 ~ 99.9)	278.18 (204 ~ 416)	0	0	0	100
		RCS(㎎/㎥)	58	2.06	3.23	0.10	17.6	100	99.9 (99.6 ~ 99.9)	14.17 (10 ~ 22.3)	0	0	0	100
	Plastering	RD(㎎/㎥)	35	0.37	1.86	0.086	1.07	0	0.04 (<0.001 ~ 0.4)	1.02 (0.81 ~ 1.41)	0	96.5	3.5	0
		RCS(㎎/㎥)	35	0.003	2.86	0.0002	0.027	0	0.55 (<0.1 ~ 2.5)	0.0195 (0.013~0.034)	0	77.6	22.3	0.1

* Estimated Exc. Frac(%) and 95%il conc. calculated by IHDA for Bayesian decision analysis. V 1.36 (Hewett, 2011)_prior exposure rating was applied to 0.2 for all categories

** Category 0, 1, 2, 3 or 4 exposure. the categories were adapted from the AIHA exposure category system (0) negligible or trivial exposure ($X_{0.95}$ <1% OEL), (1) highly controlled ($X_{0.95}$ <10% OEL), (2) well controlled ($X_{0.95}$ <50% OEL), (3) controlled ($X_{0.95}$ <100% OEL), (4) poorly controlled ($X_{0.95}$ >100% OEL)

※ Conc, Concentration; Exc Frac., Fraction of exceeding the OEL ※ OEL: respirable EC (20 ㎍/㎥), RCS (0.05 ㎎/㎥), RD (3 ㎎/㎥)

Table 7-1. Bayesian decision analysis probability(%) and exposure risk of exceeding the OEL by construction job type

Job	Task	Hazards	n	GM	GSD	Min	Max	Exc. Frac (%)	Estimated Exc. Frac(%) (95%LCL-UCL)	Estimated 95%ile conc. (95%LCL-UCL)	Bayesian decision Analysis* Exposure Rating (posterior) Decision probability (%) ($X_{0.95}$) Category** (1)	(2)	(3)
Construction Painter	Rooftop	TVOCs (EI)	42	0.57	2.89	0.065	2.96	33.3	29.9 (21.3 ~ 40)	3.29 (2.29 ~ 5.4)	0	0	0
	Ground floor		16	0.82	1.62	0.48	3.4	25.0	34.4 (20.5 ~ 51.4)	1.81 (1.42 ~ 2.79)	0	0	0
	Pilot floor		12	0.89	1.48	0.43	1.7	33.3	37.9 (21.5 ~ 57.4)	1.69 (1.34 ~ 2.59)	0	0	0
	Bathroom		8	1.40	1.82	0.48	2.18	75.0	71.2 (46.5 ~ 88)	3.76 (2.49 ~ 9.48)	0	0	0
	Swimming pool		10	1.37	2.96	0.41	5.8	60.0	61.4 (40 ~ 79.2)	8.15 (4.12 ~ 32.1)	0	0	0
Construction welder	Pipefitter (general)	Welding fume (㎎/㎥)	21	4.75	3.15	0.15	53.1	57.1	48.23 (34.4 ~ 62.3)	31.36 (18.5 ~ 72.1)	0	0	0
	Pipefitter (chemical)		84	0.71	2.89	0.096	11.76	8.3	3.29 (1.7 ~ 6.2)	4.07 (3.12 ~ 5.66)	0	0.1	83.9
	Boilermaker (incinerator)		33	1.38	2.37	0.35	6.22	15.15	6.79 (2.9 ~ 14.4)	5.71 (4.11 ~ 9.1)	0	0	22.8
	Ironworker		9	3.77	1.82	1.5	7.18	44.4	31.8 (14.9 ~ 54.8)	10.09 (6.8 ~ 23.2)	0	0	0
	Metal finishing		35	0.78	2.07	0.15	2.32	0	0.55 (<0.1 ~ 2.5)	2.59 (1.98 ~ 3.79)	0	36.5	62.9

* Estimated Exc. Frac(%) and 95%il conc. calculated by IHDA for Bayesian decision analysis. V 1.36 (Hewett, 2011)_prior exposure rating was applied to 0.2 for all categories

** Category 0, 1, 2, 3 or 4 exposure. the categories were adapted from the AIHA exposure category system (0) negligible or trivial exposure ($X_{0.95}$ <1% OEL), (1) highly controlled ($X_{0.95}$ <10% OEL), (2) well controlled ($X_{0.95}$ <50% OEL), (3) controlled ($X_{0.95}$ <100% OEL), (4) poorly controlled ($X_{0.95}$ >100% OEL)

※ Conc., Concentration; Exc Frac., Fraction of exceeding the OEL ※ OEL: TVOC (EI =1), Welding fume (5 ㎎/㎥)

Table 7-1. Bayesian decision analysis probability(%) and exposure risk of exceeding the OEL by construction job type

Job	Task	Hazards	n	GM	GSD	Min	Max	Exc. Frac (%)	Estimated Exc. Frac(%) (95%LCL-UCL)	Estimated 95%ile conc. (95%LCL-UCL)	Bayesian decision Analysis* Exposure Rating (posterior) Decision probability (%) ($X_{0.95}$) Category** (1)	(2)	(3)	(4)
Road paver	Paver operator	Asphalt fume (㎍/㎥)	6	41.6	3.66	5.35	259	0	2.76 (0.1 ~ 24.6)	351.0 (129 ~ 5,100)	0	46.3	40.6	13.1
	Road paver		24	42.32	2.39	13.1	309	0	0.23 (<0.1 ~ 2.0)	177.0 (121 ~ 315)	0	82.3	17.3	0.4
	Macadam roller		8	31.9	2.66	10.6	172	0	0.25 (<0.1 ~ 7.8)	160 (81.5 ~ 722)	0.1	78.6	19.2	2.1
	Tire roller		4	30.3	1.79	21.3	72.1	0	0 (<0.1 ~ 6.3)	78.7 (46.6 ~ 599)	6	84.3	7.9	1.8

* Estimated Exc. Frac(%) and 95%il conc. calculated by IHDA for Bayesian decision analysis. V 1.36 (Hewett, 2011)_prior exposure rating was applied to 0.2 for all categories

** Category 0, 1, 2, 3 or 4 exposure. the categories were adapted from the AIHA exposure category system (0) negligible or trivial exposure ($X_{0.95}$ <1% OEL), (1) highly controlled ($X_{0.95}$ <10% OEL), (2) well controlled ($X_{0.95}$ <50% OEL), (3) controlled ($X_{0.95}$ <100% OEL), (4) poorly controlled ($X_{0.95}$ >100% OEL)

※ Conc., Concentration; Exc Frac., Fraction of exceeding the OEL ※ OEL: Asphalt fume (500 ㎍/㎥)

Table 7-2 (a). The variability of respirable EC concentrations (㎍/㎥) among excavation workers

Job	Task	Company	Day1		Day2		Day3		Within company (Day to day variation)		Between company	
			n	GM (GSD)	n	GM (GSD)	n	GM (GSD)	n	GM (GSD)	n	GM (GSD)
Excavation workers	Inside excavator	A	3	5.52 (1.57)	3	3.23 (1.48)	-	-	6	4.23 (1.62)	23	8.69 (2.43)
		B	3	10.03 (1.28)	3	9.95 (1.37)	-	-	6	9.99 (1.29)		
		C	2	46.7 (1.37)	3	19.2 (1.46)	-	-	5	27.41 (1.78)		
		D	3	7.77 (2.19)	3	4.58 (2.79)	-	-	6	5.97 (2.38)		
	Outside excavator	A	3	5.67 (1.48)	3	3.63 (1.16)	-	-	6	4.54 (1.44)	30	33.20 (3.62)
		B	3	51.29 (1.17)	3	56.91 (1.20)	3	71.6 (1.09)	9	59.34 (1.22)		
		C	3	147.24 (1.37)	3	96.8 (1.18)	3	108 (1.14)	9	115.7 (1.31)		
		D	4	14.9 (2.31)	2	17.15 (1.08)	-	-	6	15.62 (1.92)		

Table 7-2 (b). The variability of TVOCs concentrations among construction painters

Job	Task	Company	Day1		Day2		Day3		Day4		Within company (Day to day variation)		Between company	
			n	GM (GSD)	n	GM (GSD)	n	GM (GSD)	n	GM (GSD)	n	GM (GSD)	n	GM (GSD)
Construction painters	Rooftop	A	5	0.43 (1.11)	-	-	-	-	-	-	5	0.43 (1.11)	42	0.57 (2.89)
		D	5	0.22 (2.63)	5	0.29 (2.54)					10	0.25 (2.47)		
		E	7	0.84 (3.16)	6	1.19 (1.80)	10	0.41 (2.58)	4	2.48 (1.19)	27	0.81 (2.84)		
	Ground floor	B	10	0.80 (1.39)	-	-	-	-	-	-	10	0.80 (1.39)	16	0.82 (1.62)
		H	6	0.87 (2.02)	-	-	-	-	-	-	6	0.87 (2.02)		
	Pilot floor	G	6	1.04 (1.43)	6	0.75 (1.46)	-	-	-	-	12	0.89 (1.48)	12	0.89 (1.48)
	Bathroom	F	4	1.41 (1.77)	4	1.39 (2.05)	-	-	-	-	8	1.40 (1.82)	8	1.4 (1.82)
	Swimming pool	C	10	1.37 (2.96)	-	-	-	-	-	-	10	1.37 (2.96)	10	1.37 (2.96)

Table 7-2 (c). The variability of respirable crystalline silica concentrations (㎎/㎥) among concrete finishers

Job	Task	Company	Day1		Day2		Day3		Within company (Day to day variation)		Between company	
			n	GM (GSD)	n	GM (GSD)	n	GM (GSD)	n	GM (GSD)	n	GM (GSD)
Concrete finisher	Chipping	A	3	0.064 (1.6)	-	-	-	-	3	0.064 (1.6)	36	0.12 (4.13)
		B	1	0.092	2	0.495 (2.28)	-	-	3	0.28 (3.11)		
		D	3	0.049 (26.04)	2	0.055 (1.02)	3	0.022 (2.27)	8	0.037 (6.37)		
		E	4	0.09 (2.43)	4	0.368 (1.66)	2	0.140 (1.28)	10	0.17 (2.46)		
		G	4	0.19 (1.97)	4	0.103 (4.21)	2	0.283 (1.07)	10	0.16 (2.74)		
		H	2	0.59 (10.2)	-	-	-	-	2	0.59 (10.2)		
	Grinding	A	3	1.41 (2.29)	9	2.825 (2.89)	6	8.01 (2.11)	18	3.56 (2.97)	58	2.06 (3.23)
		B	-	-	2	2.36 (2.69)	4	3.19 (3.16)	6	2.88 (2.74)		
		C	-	-	-	-	2	3.48 (1.35)	2	3.48 (1.35)		
		D	4	0.66 (2.98)	4	1.44 (2.22)	-	-	8	0.98 (2.66)		
		E	-	-	-	-	2	0.47 (1.09)	2	0.47 (1.09)		
		F	2	2.44 (1.14)	4	1.76 (1.34)	2	0.89 (1.91)	8	1.62 (1.65)		
		G	1	0.144	1	0.104			2	0.12 (1.26)		
		H	2	3.23 (1.61)	6	2.31 (4.41)	4	3.34 (1.33)	12	2.76 (2.83)		
	Plastering	C	-	-	2	0.024 (1.18)	1	0.007	3	0.016 (2.13)	35	0.003 (2.86)
		D	3	0.007 (1.63)	2	0.004 (2.69)	2	0.002 (2.18)	7	0.004 (2.18)		
		E	1	0.005	1	0.003	1	0.008	3	0.005 (1.66)		
		F	6	0.003 (2.33)	4	0.001 (4.29)	6	0.002 (2.65)	16	0.002 (2.77)		
		G	2	0.004 (1.13)	2	0.002 (1.67)	2	0.004 (2.79)	6	0.004 (2.42)		

Table 7-2 (d). The variability of welding fume concentrations (mg/m^3) among construction welders

Job	Task	Company	Day1 n	Day1 GM (GSD)	Day2 n	Day2 GM (GSD)	Day3 n	Day3 GM (GSD)	Within company (Day to day variation) n	Within company (Day to day variation) GM (GSD)	Between company n
Construction welder	Pipefitter (general)	A	1	0.15	2	2.08 (4.36)	2	3.01 (4.70)	5	1.43 (4.70)	21
		B	4	4.97 (1.39)	3	1.30 (1.62)	3	5.24 (1.28)	10	4.83 (1.39)	
		C	2	27.21 (2.57)	1	12.56			3	21.03 (2.23)	
		D	1	8.36	1	6.39	1	7.85	3	7.48 (1.15)	
	Pipefitter (chemical)	E	28	0.74 (3.09)	28	0.80 (3.03)	28	0.61 (2.60)	84	0.71 (2.89)	84
	Boilermaker (incinerator)	F	11	1.20 (2.24)	11	1.42 (2.63)	11	1.55 (2.38)	33	1.38 (2.37)	33
	Ironworker	G	3	3.94 (2.32)	3	3.96 (1.81)	3	3.42 (1.81)	9	3.77 (1.82)	9
	Metal finishing	A	13	0.73 (2.30)	11	1.01 (1.77)	11	0.67 (2.08)	35	0.78 (2.07)	35

Table 7-2 (e). The variability of asphalt fume concentrations ($\mu g/m^3$) among road pavers

Job	Task	Company	Within company (Day to day variation) n	Within company (Day to day variation) GM (GSD)	Between company n	Between company GM (GSD)	Task	Company	Within company (Day to day variation) n	Within company (Day to day variation) GM (GSD)	Between company n
Road paver	Paver operator	A	2	128.4 (2.70)	6	41.57 (3.66)	Macadam roller	A	2	21.3 (1.05)	8
		B	2	28.7 (1.41)				B	3	31.0 (3.56)	
		C	2	19.5 (6.23)				C	3	42.9 (3.32)	
	Road paver	A	8	29.2 (1.66)	24	42.32 (2.39)	Tire roller	A	2	39.2 (2.37)	4
		B	8	29.9 (1.74)				B	1	23.9	
		C	8	86.8 (2.77)				C	1	23.0	

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Appendix Ⅰ. Representative construction job types; job dsecription, major activities and exposure hazards

No	Job type	Job description	Major activities	Exposure hazards
1	Excavation worker	Craftsmen who are engaged in the work of excavating and completing the space to the ground surface necessary for constructing a foundation or basement.	Ground drilling, Pile driving, Soil excavation, Ground cutting, Rock blasting, Earth anchoring, Grouting, Earth support installation (welding), Braced wall installation (wooden plank), etc.	Noise, Whole body vibration, Diesel engine exhaust, Cement/Concrete dust, Crystalline silica,
2	Road paver workers	Craftsmen who are engaged in the work of laying pavement and aggregates that flatten the road surface by reinforcing it with asphalt mixture or concrete.	Asphalt road pavement, Concrete road pavement	Noise, Whole body vibration, Diesel engine exhaust, Asphalt fume, Cement/Concrete dust.
3	Concrete form workers	Craftsmen who are manufactures, assembles, installs, and dismantles molds and supports for concrete pouring	Mold installation, Mold dismantling, Oil-based seperating agent application	Noise, Cement/Concrete dust, Welding fume, Volatile organic compounds
4	Architecture carpenters	Craftsmen who are engaged in the construction of buildings and the production, installation, or dismantling of indoor wooden structures, and finishing the interior of the building by using a decorative material.	Wood cutting, Wood planer work, Wood preservatives application, Wooden construction	Noise, Wood dust, Wood preservative(copper), Glass fiber, Gypsum dust

Appendix Ⅰ. Representative construction job types; job dsecription, major activities and exposure hazards_continued

No	Job type	Job description	Major activities	Exposure hazards
5	Bricklayer	Craftsmen who are engaged in stacking and dismantling bricks and blocks, and filling gaps in walls and walls with mud.	Installation and dismantling of bricks and blocks Agitation (mixing) of sand, cement, mortar, etc., Mud filling work	Noise, Cement/Concrete dust, Crystalline silica.
6	Plasters	Craftsmen who work on the interior and exterior surfaces of structures using cement, mortar, plaster, plaster, plaster, and other plasters.	Agitation (mixing) of sand, cement, mortar, etc., Plastering work	Cement/Concrete dust, Crystalline silica.
7	Concrete finisher	Craftsmen who smooth and finish surfaces of poured concrete, such as floors, walks, sidewalks, roads, or curbs using a variety of hand and power tools.	Concrete chipping, Concrete grinding	Noise, Vibration, Cement/Concrete dust, Crystalline silica.
8	Water proofing workers	Craftsmen who engaged in the work to prevent leakage of the structure's floor, wall, roof, etc.	Base surface treatment (concrete base treatment), Paint mixing work, Urethane primer and resin application, Cement mortar waterproofing, Asphalt sheet waterproofing	Noise, Vibration, Cement/Concrete dust, Crystalline silica, Volatile organic compounds, Urethane, Isocyanates

Appendix Ⅰ. Representative construction job types; job dsecription, major activities and exposure hazards_continued

No	Job type	Job description	Major activities	Exposure hazards
9	Cauking /Tile setters	Craftsmen who engaged in the work of putting a filler in a small gap for watertightness or airtightness with an adhesive or adhesive material for waterproofing or fixing window frames and bathtubs, A craftsman who attaches tiles such as tiles or asyls to the surface of the structure using adhesive	Sealant (butyl, acrylic, urethane, silicone, acetic acid-free, etc.) injection, Mixing and attaching tile adhesives (white cement, mortar, etc.), Tile attachment (floating, pressing, adhesion, adhesion method)	Volatile organic compounds, Noise, Cement dust.
10	Stone mason	Craftsmen who is engaged in the main work of constructing structures by attaching stones and stones formed by processing stones or by performing general stacking	Stone (marble, etc.) cutting and polishing Stone fixing and attaching(cement or epoxy adhesive)	Noise, Vibration, Crystalline silica, Cement dust. Epoxy
11	Painter	Craftsmen who engaged in the work of painting walls, equipment, buildings, bridges, and other structural surfaces, using brushes, rollers, and spray guns.	Oil-based painting, Water-based painting, Epoxy resin painting	Volatile organic compounds, Epoxy, Isocyanate, Metals(lead, Titanium dioxide)
12	Rebar Workers	Craftsmen who engaged in the work of positioning and securing steel bars or mesh in concrete forms in order to reinforce concrete.	Rebar cutting, bending and welding	Noise, Metal fumes, Ultraviolet ray

Appendix Ⅰ. Representative construction job types; job dsecription, major activities and exposure hazards_continued

No	Job type	Job description	Major activities	Exposure hazards
13	Structural Iron and Steel Workers	Craftsmen who raise, place, and unite iron or steel girders, columns, and other structural members to form completed structures or structural frameworks.	Steel frame assembly and dismantling, Steel deck plate installation	Noise, Metal fumes, Ultraviolet ray
14	Concrete workers	Craftsmen who chops or sprays shotcrete using cement, sand, gravel, water rub and pour and vibretta to make concrete of the desired weight and volume	Concrete delivery work with pump car and pressure pipe, Concrete pouring work in the formwork, Shotcrete spraying, Concrete curing (hot air, solid fuel, etc.)	Noise, Whole body vibration, Diesel engine exhaust, Wet cement, Concrete dust
15	Sash workers (carpenters)	Craftsmen who engaged in manufacturing or installing windows and doors from wood, steel, sash, etc. in a building, and a craftsman engaged in manufacturing or installing wooden windows and doors in a building	Window(wood, aluminium, PVC, steel) installation and fixing, Sealant (butyl, acrylic, urethane, silicone, acetic acid-free, etc.) injection, Insulation construction (use of urethane foam filler)	Noise, Wood dust, Welding fume, Volatile organic compounds, Urethane, Isocyanates
16	Scaffolding worker	Craftsmen who engaged in the installation and dismantling of scaffolds, carriers, workbenches, protective nets, etc.	Scaffold assembly and dismantling	Noise, Welding fume, Cement/Concrete dust

Appendix Ⅰ. Representative construction job types; job dsecription, major activities and exposure hazards_continued

No	Job type	Job description	Major activities	Exposure hazards
17	Interior worker/ Glaziers	Craftsmen who finishes with interior materials in building, Craftsmen who install glass in windows, skylights, store fronts, and display cases, or on surfaces, such as building fronts, interior walls, ceilings, and tabletops.	Attachment and detachment of interior materials, Glass cutting, installation, decoration, Insulation, plasterboard work	Noise, Volatile organic compounds, Epoxy, Isocyanate, Glass fiber, Gymsum dust
18	Plumber	Craftsmen who assemble, install, alter, and repair pipelines or pipe systems that carry water, steam, air, or other liquids or gases. May install heating and cooling equipment and mechanical control systems	Piping installation, repair, Pipe welding	Noise, Metal fumes, Ultraviolet ray
19	Insulation Workers	Craftsmen who apply insulating materials to pipes or ductwork, or other mechanical systems in order to help control and maintain temperature.	Cutting and bonding of insulation materials	Volatile organic compounds, Epoxy, Isocyanate, Glass fiber dust
20	Demolition worker	Craftsmen who engaged in the general work of carrying out the process of removing (collecting, transporting, processing) all the wastes generated while dismantling the structure (apartments, houses, underground structures and facilities),	Dismantling of buildings (asbestos, concrete, wooden structures, metal structures, etc.)	Noise, Asbestos, Concrete dust, Wood dust, Metal fumes, Metals

Appendix Ⅰ. Representative construction job types; job dsecription, major activities and exposure hazards_continued

No	Job type	Job description	Major activities	Exposure hazards
21	Welder	Craftsmen who welds steel frame, pipe or equipment on construction site	Welding of building piping and facilities, etc.; Carbon steel, Stainless steel, Alloy	Noise, Metal fumes, Ultraviolet ray, Metals(iron oxide, zinc oxide, manganese, chromium, nickel, etc)
22	Electrician	Craftsmen who engaged in main tasks such as electricity and communication work Craftsman engaged in the main electrical work of structures or temporary facilities	Electrical equipment repair Indoor switchboard installation Transmission, distribution, substation, cable work	Noise, Metal fumes
23	Construction machine mechanic	Mechanic operates various construction machines	Machine facility assembly, installation, adjustment, inspection, and maintenance	Noise, Metal fumes, Metals
24	Construction equipment operators	Craftsmen who operate one or several types of power construction equipment, - such as motor graders, bulldozers, scrapers, compressors, pumps, derricks, shovels, tractors, or front-end loaders to excavate, move, and grade earth, erect structures, or pour concrete or other hard surface pavement.	Construction machinery operation	Noise, Whole body vibration, Diesel engine exhaust,

Appendix Ⅰ. Representative construction job types; job dsecription, major activities and exposure hazards_continued

No	Job type	Job description	Major activities	Exposure hazards
25	Landscaper	Craftsmen who engaged in the main task of artificially decorating natural scenery using trees, flowers, and stones.	Planting trees, grass, etc. Pesticide spraying work Landscaping facility construction	Noise, Other mineral dust Pesticide(Volatile organic compounds)
26	Construction divers	Craftsmen who enters the water for construction of bridges, ports, etc. and works with the operator of a crane and collecting rocks.	Underwater construction work	Noise, High pressure
27	Rock blaster	Craftsmen who is engaged in drilling into the bedrock using memorization, Craftsmen who drills a hole in the rock and uses explosives to break the rock.	Blasting drilling, blasting agent injection, blasting, rock treatment	Noise, Vibration, Cement/Concrete dust, Crystalline silica.

Appendix Ⅱ. Recent 10 year's occupational disease among construction workers in Korea by job types

Job type	Physical agent				Biological	Chemical agent									
	Noise	Heat wave	High Pressure	Vibration	Bacteria, Virus	Cancer	Asbestos	Skin disease	Organic compounds	Solvents	Mercury	Benzane	Toxic Hepatitis	Asthma	Chromium
Total	*145*	*75*	*42*	*4*	*124*	*77*	*57*	*26*	*14*	*3*	*12*	*6*	*2*	*2*	*1*
Excavating worker (Rock boring, blasting)	48	2		4	5	11									
General Laborer	14	31			9	3	4						1		
Diver		1	42		1										
Concrete finisher	23					10	1	1							
Welders (pipefitter)	9	2			3	6	9		2			2			1
Demolition worker	3	5			1	1	10	1			12				
Stonemason	7					11		1							
Painter (waterproof)	2	1				3		2	3	3		3	1	2	
Insulation Workers	1				1	5	14		1						
Concrete worker	2	3			3			4	3						
Steel worker	2				8										
Electrician	1					2	4								
Scaffolding worker	1	2				3	1	1							
Mechanics	2				1		3	2							

Appendix Ⅱ. Recent 10 year's occupational disease among construction workers in Korea by job types_continued

Job type	Physical agent				Biological	Chemical agent											Total
	Noise	Heatwave	High Pressure	Vibration	Bacteria, Virus	Cancer	Asbestos	Skin disease	Organic compounds	Solvents	Mercury	Benzane	Toxic Hepatitis	Asthma	Chromium	Others	
Concrete form worker	1	5			2												8
Rebar Workers	1	5			1												7
Equipment operators	2				1	1	1										5
Manager	1				1	1	2										5
Panel worker		4			1												5
Plant worker						3	1		1								5
Machine mechanic	3	1															4
Carpenters		2				1	1										4
Interior worker						1	1										2
Bricklayer		1															1
Tile setter						1											1
Road paver		1															1
Landscaper		6			72												78
Others	22	3			14	14	5	14	4			1				6	83

Appendix Ⅲ. Literature review of occupational disease among construction workers_*Occupational cancer*

No	Author	Year	Title	Journal	Participants	Study design	Exposure (comparison)	Outcome	Results
1	Alicandro G, et al.	2019	Mortality among Italian male workers in the construction industry: a census-based cohort study.)	Eur J Public Health. 2019 Sep 3	1,068,653 construction workers based on the 2011 Italian census and the mortality archives (2012-2015)	Record-linkage cohort study	Non-manual workers and manual workers in other industries	MRR (Mortality rate ratios) using Poisson regression models	* Compared with non-manual workers - all neoplasms (MRR 1.30), head and neck (MRR 2.05), stomach (MRR 1.56), liver (MRR 1.62), lung(MRR 1.80), prostate (MRR 1.24) and bladder (MRR 1.60) cancers, respiratory (MRR 1.41) and liver (MRR 1.79) diseases, all external causes (MRR 1.87), falls (MRR 2.87) and suicide (MRR 1.58) * Compared with manual workers in other industries - prostate (MRR 1.27) and non-melanoma skin cancers (MRR 1.95), all external causes (MRR 1.14), falls (MRR 1.94) and suicide (MRR 1.18)
2	Stocks SJ et al.	2011	Occupation and work-related ill-health in UK construction workers.	Occup Med (Lond). 2011 Sep;61(6): 407-15.	Constructionrelatedoccupationintheukfrom2002-2008	THOR (The Health and Occupation Reporting network) data	Employed in UK construction industry (All other employment sectors)	SRRs (Standadised incidennce rate ratios)	* Respirable disease (mesothelioma, pneumoconiosis, lung cancer, non-malignant pleural disease)_SRR -Managers in construction SRR 7.2 (3.3 ~ 15.8), Drafts person SRR 3.5 (1.2 ~ 9.7), Pipefitters SRR 4.5 (3.2 ~ 6.2), Metal working production SRR 1.4 (1.2 ~ 1.6), Electricians SRR 2.7 (2.4 ~ 3.2), Scaffolders SRR 12 (8 ~ 18), Plumbing, heating and ventilating engineer SRR 2.3 (1.9 ~ 2.7), Construction mechanics SRR 8.3 (6.3 ~ 11.0), Carpenters SRR 3.3 (2.6 ~ 4.1), Laborers other construction tradesn.e.c. SRR 25 (20 ~ 31), Skilled construction and building trade SRR 1.9 (1.6 ~ 2.1)

Appendix Ⅲ. Literature review of occupational disease among construction workers_*Occupational cancer*

No	Author	Year	Title	Journal	Participants	Study design	Exposure (comparison)	Outcome	Results
3	Stocks SJ et al.	2010	The incidence of medically reported work-related ill health in the UK construction industry.	Occup Environ Med. 2010 Aug;67(8):574-6.	Employed in UK construction industry	THOR (The Health and Occupation Reporting network) data	Employed in construction trade (All other employment sectors)	SRRs (Standardised incidennce rate ratios) of Lung cancer	by Industry SRR (age < 65) *Lung cancer SRR 5.4 (3.2 ~ 8.9) by Trade SRR (age < 65) *Lung cancer SRR 9.1 (5.7 ~ 14.5)
4	Dement JM et al.	2009	Mortality of older construction and craft workers employed at Department of Energy (DOE) nuclear sites.	Am J Ind Med. 2009 Sep;52(9):671-82	A cohort of 8,976 former construction workers	Cohort study	A cohort of 8,976 former construction workers	Cause-specific SMRs (Standardized mortality ratios)	All cancers (SMR 1.28, 95% CI 1.13 ~ 1.45) * Lung cancer (SMR 1.54, 95% CI 1.24 ~ 1.87) * Mesothelioma(SMR 5.93, 95% CI 2.56 ~ 11.68) * Asbestosis(SMR 33.89, 95% CI 18.03 ~ 57.95) * Chronic obstructive pulmonary disease(COPD) (SMR 1.92, 95% CI 1.02 ~ 3.29).

Appendix Ⅲ. Literature review of occupational disease among construction workers_*Occupational cancer*

No	Author	Year	Title	Journal	Participants	Study design	Exposure (comparison)	Outcome	Results
5	Arndt V et al.	2005	Construction work and risk of occupational disability: a ten year follow up of 14,474 male workers.	Occup Environ Med. 2005 Aug;62(8):559-66.	14,474 male workers from the construction industry in Germany aged 25-64 (heath examination 1986-1992)	Cohort study	Construction workers(n=95 /14,474) (General workforce)	SIR(Standadised incidennce ratios) of Cancer	Cancer SIR 1.26 (1.08 ~ 1.47) Cancer of the oral and cabity and pharynx SIR 1.84 (1.22 ~ 2.66) Cancer of the digestive system SIR 1.25 (0.91 ~ 1.67) Cancer of the respiratory system SIR 1.02 (0.70 ~ 1.44) Cancer of urogenial system SIR 1.48 (0.99 ~ 2,12)
6	Arndt V et al.	2004	All-cause and cause specific mortalityin a cohort of 20 000 construction workers; results from a 10 year follow up.	Occup Environ Med. 2004 May;61(5):419-25.	19,943 male employees in German construction industry (heath examination 1986-1992 followed up until 1999/2000) ten years follow up	Cohort study	Construction workers	SMR(Standadised mortality ratio) of Cancer	Cancer SMR 0.89 (0.79 ~ 1.00) Cancer of the oral and cabity and pharynx SMR0.86(0.54 ~ 1.29) Cancer of the digestive system SMR0.89(0.72-1.08) Cancer of the respiratory system SMR1.01(0.82 ~ 1.22) *Cancer by trade_SMR -Plumber SMR 1.04 (0.71 ~ 1.45) -Carpentrs SMR 0.68 (0.46 ~ 0.97) -Painters SMR 0.91 (0.66 ~ 1.20) -Plasters SMR 0.89 (0.61 ~ 1.22) -Bricklayers SMR 0.86 (0.70 ~ 1.04) -laborers SMR 1.05 (0.78 ~ 1.36)

Appendix Ⅲ. Literature review of occupational disease among construction workers_*Occupational cancer*

No	Author	Year	Title	Journal	Participants	Study design	Exposure (comparison)	Outcome	Results
7	Sun J et al.	2002	Mortality among Japanese construction workers in Mie Prefecture.	Occup Environ Med. 2002 Aug;59(8):512-6.	17,668 members of the construction workers's health insurance society (2 April 1973 to 1 April 1998)	Cohort study	Construction workers (Administrative workers)	SMR of Cancer	*Carpenters All malignant neoplasm SMR 0.99(0.87-1.12), Cancer of oesophagus SMR 0.96(0.41-1.88), Cancer of stomach SMR 0.97(0.75-1.23) Cancer of liver SMR 0.96 (0.70-1.29) Cancer of pancreas SMR 0.86(0.47-1.44) Cancer of trachea, bronchus, and lung SMR 1.02(0.77-1.33) *Plasters All malignant neoplasm SMR 1.11(0.82-1.47), Cancer of stomach SMR 1.21(0.67-2.03) Cancer of liver SMR 0.53 (0.14-1.35), Cancer of pancreas SMR 0.37(0.01-2.06) Cancer of trachea, bronchus, and lung SMR 1.61(0.86-2.75) *Ironworkers All malignant neoplasm SMR 1.14(0.72-1.71), Cancer of stomach SMR 0.40(0.05-1.46), Cancer of liver SMR 1.27 (0.41-2.97), Cancer of pancreas SMR 1.55(0.19-5.58) Cancer of trachea, bronchus, and lung SMR 2.88(1.44-5.15)
8	Sun J et al.	1997	A cohort study of construction workers	American J Indus Med. 1997;32:35-41	17,668 members of the construction workers's health insurance society (2 April 1973 to 1 April 1998)	Cohort study	Construction workers (Administrative workers)	SMR of Cancer	All malignant neoplasm SMR 1.13(0.97-1.30) Cancer of stomach SMR 1.03(0.78-1.33) Cancer of liver SMR 1.09(0.70-1.62) Cancer of pancreas SMR 1,26(0.65-2.21) Cancer of trachea, bronchus,and lung SMR1.25(0.88-1.74)

Appendix Ⅲ. Literature review of occupational disease among construction workers_*Occupational cancer*

No	Author	Year	Title	Journal	Participants	Study design	Exposure (comparison)	Outcome	Results
9	Keller JE et al.	1993	Cancer in Illinois construction workers: a study.	Am J Ind Med. 1993 Aug;24(2):223-30	Subjects from the Illinois State Cancer Registr	Case-control study	-	Odds Ratio (OR)	-Gastric cancer and welding work (OR 2.11, 95% CI 1.09 ~ 4.09) -Employment in lung cancer and construction industry (OR 1.18, 95% CI 1.02 ~ 1.26) -Lung cancer and welding work (OR 1.68, 95% CI 1.03 ~ 2.76) -Colon cancer and welding work (OR 0.54, 95% CI 0.29~1.00) -Prostate cancer and construction employment (OR 0.76, 95% CI 0.65~0.89) -Prostate cancer and piping work (OR 0.44, 95% CI 0.38~0.50) -Prostate cancer and metal processing (OR 0.43, 95% CI 0.19~0.93) -Bladder cancer and electrician employment (OR 0.60, 95% CI = 0.36~1.00)
10	Jung JKH et al.	2018	Examining lung cancer risks across different industries and occupations in Ontario, Canada: the establishment of the Occupational Disease Surveillance System.	Occup Environ Med. 2018 Aug;75(8):545-552	The Occupational Disease Surveillance System (ODSS)_During the 1983 to 2014 follow-up, 34 661 workers in the cohort were diagnosed with lung cancer.	Cohort study	Construction	HR (Cox proportional hazard models)	HRs 1.09 (99% CI 1.04-1.14) * High risk observed among workers in the quarry/sand pit and construction industry and men in metal mines, iron castings, non-metallic minerals and transport industries. * Excessive dangers are observed in occupations in the fields of drilling/blasting, other mining/quarrying, mineral ore processing, excavation/grading/paving, truck driving, painting, bus driving and construction.

Appendix Ⅲ. Literature review of occupational disease among construction workers_*Occupational cancer*

No	Author	Year	Title	Journal	Participants	Study design	Exposure (comparison)	Outcome	Results
11	Lacourt A et al.	2015	Lung cancer risk among workers in the construction industry: results from two case-control studies in Montreal.	BMC Public Health. 2015 Sep 22;15:941	1,593 lung cancer cases and 1,427 controls	Case-control study	Ever in the construction industry(Never in the construction industry)	OR (Odds Ratio)	*Lung Cancer -Ever in the construction industry OR 1.15(0.94-1.41) -Building, industrial ,heavy construction OR 1.26(0.98-1.62) -Trades contracting OR 1.02(0.78-1.33)
12	Consonni D et al.	2015	Lung cancer risk among bricklayers in a pooled analysis of case-control studies	Int J Cancer. 2015 Jan 15;136(2):360-71	Among 15,608 cases and 18,531 controls, there were 695 cases and 469 controls who had ever worked as bricklayers (OR: 1.47; 95% CI: 1.28-1.68)	-	Bricklayers	OR (Odds Ratio)	*Squamous (OR 1.68, 95% CI 1.42-1.98, 309 cases) *Small cell carcinomas (OR 1.78, 95% CI 1.44-2.20, 140 cases), *Adenocarcinoma (OR 1.17, 95% CI 0.95-1.43, 150 cases)

Appendix Ⅲ. Literature review of occupational disease among construction workers_*Occupational cancer*

No	Author	Year	Title	Journal	Participants	Study design	Exposure (comparison)	Outcome	Results
13	Consonni D et al.	2012	Increased lung cancer risk among bricklayers in an Italian population-based case-control study.	Am J Ind Med. 2012 May;55(5):423-8.	The EAGLE (Environment And Genetics in Lung cancer Etiology) study	Population-based case-control study conducted in Italy between 2002 and 2005.	Bricklayers	OR (Odds Ratio)	Lung cancer risk for bricklayers (OR 1.57, 95% CI 1.12-2.21; 147 cases, 81 controls).
14	Järvholm B et al.	2014	The risk of lung cancer after cessation of asbestos exposure in construction workers using pleural malignant mesothelioma as a marker of exposure.	J Occup Environ Med. 2014 Dec;56(12):1297-301	189,896 Swedish construction workers through a linkage with the Swedish Cancer Registry.	Cohort study	Lung cancer occurrence according to asbestos exposure level (High, Medium, Low) at the time of operation and comparison of lung cancer according to past exposure level 20 years after exposure ends	RR (Relative Risk)	* Lung cancer incidence of workers in the high group exposed to asbestos during work RR 1.74 (1.25-2.41) * Lung cancer incidence of workers in the high group exposed to asbestos 20 years after the end of exposure is 0.94 (0.77-1.15)

Appendix Ⅲ. Literature review of occupational disease among construction workers_*Occupational cancer*

No	Author	Year	Title	Journal	Participants	Study design	Exposure (comparison)	Outcome	Results
15	Calvert GM et al.	2012	Lung cancer risk among construction workers in California, 1988-2007.	Am J Ind Med. 2012 May;55(5):412-22	110,937 lung cancer cases identified from the California Cancer Registry between 1988 and 2007	Case-control study	Not known to be associated with employment in the construction industry	Morbidity Odds ratios (MORs)	All lung cancer MOR 1.57(1.54-1.61) *Brickmasons MOR1.50(1.27-1.76) *Carpenters MOR1.58(1.49-1.66) *Electricians MOR1.34(1.23-1.44) *Laborers MOR1.86(1.77-1.95) *Managers and Engineers MOR 0.90(0.84-0.97) *Metal workers MOR1.60(1.35-1.89) *Operating Engineers MOR1.71(1.55-1.88) *Painters MOR 1.89(1.76-2.04) *Plumbers MOR 1.69(1.55-1.83) *Roofers MOR 2.62(2.25-3.06) *Supervisors MOR 1.06(0.99-1.13) *Welders MOR 2.16(1.81-2.58) *Other MOR 1.62(1.52-1.73)
16	Purdue MP et al.	2006	Impaired lung function andlung cancerincidence in a cohort of Swedish construction workers.	Thorax. 2007 Jan;62(1):51-6. Epub 2006 Aug 23	Cohort of male Swedish construction workers(n = 176 997) (measurement of lung capacity before follow-up) _834 Cases of lung cancer	-	-	RR (Relative Risk)	* Chronic obstructive pulmonary disease (ChronicObstructive Pulmonary Disease, COPD, mild: RR 1.5, 95% CI 1.2 to 1.9; Medium/Depth: RR 2.2, 95% CI 1.8 ~ 2.7) * Restrictive Lung Disease, RLD, RR 2.0, 95% CI 1.6 ~ 2.5 compared to normal lung function

Appendix Ⅲ. Literature review of occupational disease among construction workers_*Occupational cancer*

No	Author	Year	Title	Journal	Participants	Study design	Exposure (comparison)	Outcome	Results
17	Koskinen K et al.	2002	Different measures of asbestos exposure in estimating risk oflung cancer and mesothelioma among construction workers.	J Occup Environ Med. 2002 Dec;44(12): 1190-6.	16,696 male construction workers for cancer in 1990-2000	-	Compared to the Finnish population and relative risk (RR) in a multivariate analysis compared to the internal low exposure category for each indicator.	SIR (Standardized incidence ratios)	* Mesothelioma (SIR 2.0, 95% CI = 1.0-3.3) -Non-cancer (SIR 1.1, 95% CI = 0.9-1.2) * Radiological pulmonary fibrosis has twice the RR of lung cancer and three times higher exposure index-no risk for people with pleural plaque. * The risk of lung cancer is highest in the warmer (RR 3.7, 95% CI 1.4 - 9.9).
18	Tjoe Nij E, Heederik D.	2005	Risk assessment of silicosis and lung cancer among construction workers exposed to respirable quartz.	Scand J Work Environ Health. 2005;31 Suppl 2:49-56.	(1998) 1,335 people expected to have high cumulative exposure to quartz (2002) Repeated study of 96 people	-	-		* Construction workers exposed to quartz above the exposure limit have an increased risk of silicosis and other respiratory diseases.

Appendix Ⅲ. Literature review of occupational disease among construction workers_*Occupational cancer*

No	Author	Year	Title	Journal	Participants	Study design	Exposure (comparison)	Outcome	Results
19	Nakagawa H et al.	2000	Dust exposure and lung cancer mortality in tunnel workers.	J Environ Pathol Toxicol Oncol. 2000;19(1-2):99-101.	603 tunnel workers aged over 30 years in five villages and habitants without dust history	-	Dust exposure in tunnel construction industry (Habitants without dust history)	SMR(Standadised mortality ratio)	Mortality risk ratio of tunnel workers was 2.15 with that of inhabitants without dust exposure history
20	Wang X et al.	2016	Respiratory Cancer and Non-Malignant Respiratory Disease-Related Mortality among Older Construction Workers-Findings from the Health and Retirement Study.	Occup Med Health Aff. 2016;4:235. Epub 2016 May 30.	The 1992-2010 RAND Health and Retirement Study (HRS) and the HRS National Death Index_25,183 workers aged 50 years and older were examined	-	Construction workers (White-collar workers)	OR (Odds Ratio)	The risk of respiratory cancer and non-malignant respiratory disease (NMRD)-related mortality -Respiratory cancer(OR 1.65; CI 1.10-2.47) -NMRD(OR 1.73; CI 1.16-2.58)

Appendix Ⅲ. Literature review of occupational disease among construction workers_*Occupational cancer*

No	Author	Year	Title	Journal	Participants	Study design	Exposure (comparison)	Outcome	Results
21	Håkansson N et al.	2001	Occupational sunlight exposure and cancer incidence among Swedish construction workers.	Epidemiology. 2001 Sep;12(5):552-7.	323,860 men participating in an occupational health service program of the Swedish construction industry.	-	High sunlight exposure construction group(Works outdoors almost; Roofing, road construction etc) -Control:Never or seldom works outdoors(management, electricians etc)	RR (Relative Risk)	* Leukemia and lymphomas All RR 1.1(0.9-1.5) -Non-hodgkin's lymphoma RR 1.3(0.9-1.9) -Hodgkin's disease RR 0.3(0.1-0.9) -Multiple myeloma, plasmocyyoma RR 0.7(0.3-1.4) -Lympocytic leukimia RR 1.7 (0.9-3.2) -Acutel ymphocytic leukemia RR 1.5(0.2-11.9) -Chronic lymphocytic leukemia RR 1.6(0.8-3.2) -Myeloid leukemia RR 2.0(1.1-3.6) -Acute myeloid leukemia RR 2.2(1.0-4.7) -Chronic myeloid leukemia RR 2.0(0.8-5.0)
22	Binazzi A et al.	2015	Occupational exposure and sinonasal cancer: a systematic review and meta-analysis	BMC Cancer. 2015 Feb 13;15:49	Out of 63 reviewed articles, 28 (11 cohort, 17 case-control) were used in the meta-analysis	-	-	RR (Relative Risk)	An increased risk of SNC for construction (RR 1.62, 95% CI: 1.11-2.36)

Appendix Ⅲ. Literature review of occupational disease among construction workers_*Occupational cancer*

No	Author	Year	Title	Journal	Participants	Study design	Exposure (comparison)	Outcome	Results
23	Sritharan J et al.	2019	Prostate cancer risk by occupation in the Occupational Disease Surveillance System (ODSS) in Ontario, Canada.	Health Promot Chronic Dis Prev Can. 2019 May;39(5):178-186	Occupational Disease Surveillance System (ODSS). ODSS included 1,231,177 male workers for the 1983 to 2015 period,		A total of 34 997 prostate cancer cases were diagnosed among workers in ODSS	Cox proportional hazard models (age-adjusted hazard ratios and 95% CI)	Construction jobs (HR 1.09, 95% CI 1.06 ~ 1.12)
24	Zaitsu M et al.	2019	Occupational disparities in bladder cancer survival: A population-based cancer registry study in Japan.	Cancer Med. 2019 Dec 11	Population-based cancer registry (1970-2016) -identified 3,593 patients within cident bladder cancer diagnosed during 1970-2011		Compared with patients in clerical jobs	Hazard ratios (HRs) and 95% confidence intervals (CIs)	Construction jobs (HR 1.83, 95% CI 1.40 ~ 2.38)
25	Farzaneh F et al.	2017	Occupations and the Risk of Bladder Cancer in Yazd Province: A Case-Control Study.	Int J Occup Environ Med. 2017 Oct;8(4):191-198.	200 patients with bladder cancer and 200 healthy individuals in Yazd	Case-control study	Construction (Office workers)	Crude OR	Crude OR 1.76(95% CI 0.91 ~ 3.42)

Appendix Ⅳ. Literature review of occupational disease among construction workers_*Respiratory disease*

No	Author	Year	Title	Journal	Participants	Study design	Exposure (comparison)	Outcome	Results
1	Stocks SJ et al.	2011	Occupation and work-related ill-health in UK construction workers.	Occup Med (Lond). 2011 Sep;61(6):407-15.	Construction related occupation in the UK from 2002-2008	THOR (The Health and Occupation Reporting network) data	Employed in UK construction industry (All other employment sectors)	SRRs (Standadised incidennce rate ratios)	* Asthma -Welder SRR 3.8 (2.8-5.0), skilled metal and electrician SRR 1.5 (1.2-1.9) * Respirable disease (mesothelioma, pneumoconiosis, lung cancer, non-malignant pleural disease)_SRR -Managers in construction SRR 7.2(3.3-15.8) *Drafts person SRR 3.5 (1.2-9.7) *Pipefitters SRR 4.5(3.2-6.2) -Metal working production SRR 1.4(1.2-1.6) *Electricians SRR 2.7 (2.4-3.2) *Scaffolders SRR 12(8-18) -Plumbing, heating and ventilating engineer SRR 2.3 (1.9-2.7) -Construction mechanics SRR 8.3(6.3-11.0) -Carpenters SRR 3.3(2.6-4.1) -laborers other construction tradesn.e.c. SRR 25 (20-31) -Skilled construction and building trade SRR 1.9 (1.6-2.1)
2	Stocks SJ et al.	2010	The incidence of medically reported work-related ill health in the UK construction industry.	Occup Environ Med. 2010 Aug;67(8):574-6.	Employed in UK construction industry	THOR (The Health and Occupation Reporting network) data	Employed in construction trade (All other employment sectors)	SRRs (Standadised incidennce rate ratios)	SRR of male construction workers in the UK (under 65) -Respiratory* (3.8, 95% CI 3.5 ~ 4.2), Skin** (1.6, 1.4 ~ 1.8) and musculoskeletal disorders (MSD; 1.9, 1.6 ~ 2.2) * Respiratory diseases: Non-malignant pleural disease (7.1, 6.3 ~ 8.1), mesothelioma (7.1, 6.0 ~ 8.3), lung cancer (5.4, 3.2 ~ 8.9) and pneumoconiosis (5.5, 3.7 ~ 8.0), but asthma (0.09, 0.06 ~ 0.11) and mental illness health (0.3, 0.1 to 0.4) decreased. **Contact dermatitis (1.4, 1.2 ~ 1.6), neoplasm (4.2, 3.3 ~ 5.3)

Appendix Ⅳ. Literature review of occupational disease among construction workers_*Respiratory disease*

No	Author	Year	Title	Journal	Participants	Study design	Exposure (comparison)	Outcome	Results
3	Arndt V et al.	2005	Construction work and risk of occupational disability: a ten year follow up of 14,474 male workers.	Occup Environ Med. 2005 Aug;62(8):559-66.	14,474 male workers from the construction industry in Germany aged 25-64 (heath examination 1986-1992)	Cohort study	Construction workers(n=95/ 14,474) (General workforce)	SIR(Standadised incidennce ratios) of Cancer	*Respiratory system _SIR 1.27 (1.03 ~ 1.55) *Chronic obstructive pulmonary disease and related diseases _SIR1.33 (1.07-1.64) *Pneumoconiosis and other lung diseases_SIR 0.55 (0.01 ~ 3.08)
4	Anderson NJ et al	2014	Distribution of asthmaby occupation: Washington State behavioral risk factor surveillance system data, 2006-2009.	J Asthma. 2014 Dec;51(10):1035-42	41,935 respondents who were currently employed during 2006-2009	Behavioral Risk Factor Surveillance System (BRFSS) and the BRFSS Asthma Call-Back Survey (ACBS) in Washington State (WA)	Construction workers (n=1,334) (executive,administrativeandmanagerial,n=5,546)	Prevalence Ratio(PR) of Current Asthma	*Asthma PR 0.81 (95 % CI 0.55-1.18)

Appendix Ⅳ. Literature review of occupational disease among construction workers_*Respiratory disease*

No	Author	Year	Title	Journal	Participants	Study design	Exposure (comparison)	Outcome	Results
5	Ghosh RE et al.	2013	Asthma and occupationin the 1958 birth cohort.	Thorax. 2013 Apr;68(4):365-71.	9,488 members of the British 1958 birth cohort	Cohort study	Building and construction laborers(n=18/208) (office-based occupation, (n=170/2,217))	OR(Odds ratio) of Adult onset asthma	*Asthma OR 1.92 (1.12 ~ 3.27)
6	Krstev S et al.	2007	Occupationand adult-onset asthma among Chinese women in a population-based cohort.	Am J Ind Med. 2007 Apr;50(4):265-73.	1,050 women who reported a physician-diagnosed asthma as adults. Controls were 4,200 women matched to the cases by year of birth and age at diagnosis	Case-control study	Construction workers (matched to the cases by year of birth and age at diagnosis)	OR(Odds ratio) of asthma	* Ever Employment 1.56 (0.95 ~ 2.55) - < 10years: 2.17 (1.25 ~ 3.76) - > 10 years: 0.66 (0.21 ~ 2.03)
7	Jaakkola JJ et al	2003	Occupationand asthma: a population-based incident case-control study.	Am J Epidemiol. 2003 Nov 15;158(10):981-7.	Adulthood in a 1997-2000 population-based incident case-control study of 521 cases and 932 controls in south Finland	Case-control study	Construction (n=2,548/108,549)and mining workers (professionals, clerks, and administrative, (n=1,275/79,087))	Adjusted OR(Odds Ratio) of asthma	*Asthma Men OR 1.37 (0.64-2.96)

Appendix Ⅳ. Literature review of occupational disease among construction workers_*Respiratory disease*

No	Author	Year	Title	Journal	Participants	Study design	Exposure (comparison)	Outcome	Results
8	Sauni R et al.	2003	Increased risk of asthma among Finnish construction workers.	Occup Med (Lond). 2003 Dec;53(8): 527-31.	Pirkanmaa working age population (n=252,500) -7,891 Finnish construction worker	Retrospective cohort study	Construction workers (n=133/7,513) (Working age population in same region (n=1,208/123,201))	OR(Odds ratio) of Asthma	*Asthma_OR(95% CI) in comparison with the Pirkanmaa population - ALL: 1.81 (1.51-2.16) - 20-34: 1.74 (1.30-2.33) - 35-49: 1.76 (1.26-2.44) - 50-64: 2.48 (1.79-3.43)
9	Sun J et al..	2002	Mortality among Japanese construction workers in Mie Prefecture.	Occup Environ Med. 2002 Aug;59(8): 512-6.	17,668 members of the construction workers's health insurance society (April 1973 to April 1998)	Cohort study	Construction workers (Administrative workers)	SMR of Pneumonia bronchilitis	*Pneumonia bronchilitis_SMR - ALL: SMR 1.00 (0.79-1.24) - Carpenters SMR 0.99 (0.73-1.33) - Plasters SMR 1.63 (0.78-2.99) - Ironworkers SMR 1.35 (0.28-3.95)
10	Karjalainen A et al.	2002	Incidence of asthma among Finnish construction workers.	J Occup Environ Med. 2002 Aug;44(8): 752-7.	Finland Employment Population -No existing asthma and 25-59 years old	Cohort study	Construction workers (n=69/1,334) (Administrative workers,(n=448/5,546))	Incidence of Asthma	*Asthma Incidence (95%CI)/1000/year) - ALL: 1.74 (1.67-1.81) - 25-39: 1.10 (1.02-1.18) - 40-49: 1.78 (1.66-1.91) - 50-59: 3.89 (3.65-4.14)

Appendix Ⅳ. Literature review of occupational disease among construction workers_*Respiratory disease*

No	Author	Year	Title	Journal	Participants	Study design	Exposure (comparison)	Outcome	Results
11	Arndt V et al.	2004	All-cause and cause specific mortality in a cohort of 20 000 construction workers; results from a 10 year follow up.	Occup Environ Med. 2004 May;61(5):419-25.	19,943 male employees in German construction industry (heath examination 1986-1992 followed up until 1999/2000) ten years follow up	Cohort study	Construction workers	SMR(Standadised mortality ratio) of Respiratory System	* By disease -Respiratory System_SMR 0.60 (0.38-0.90) -Chronic obstructive pulmonary disease and conditions _SMR 0.55 (0.31-0.94) -Pneumoconiosis and other lung diseases_SMR 2.30 (0.48-6.74) * By occupation -Piping hole SMR 0.59 (0.07-2.13) -Woodworking SMR 0.94 (0.31-2.20) -Painter SMR 0.91 (0.11-1.60) -Plasterer SMR 0.66 (0.14-1.01) -Masonry SMR 0.36 (0.12-0.83) -Simple labor SMR 0.87 (0.28-2.01)
12	Sun J et al.	1997	A cohort study of construction workers	American J Indus Med. 1997;32:35-41	17,668 members of the construction workers's health insurance society (2April1973to1April1998)	Cohort study	Construction workers (Administrativeworkers)	SMR of Pneumonia bronchilitis	Pneumonia bronchilitis SMR 0.69 (0.32-1.32)

Appendix Ⅳ. Literature review of occupational disease among construction workers_*Respiratory disease*

No	Author	Year	Title	Journal	Participants	Study design	Exposure (comparison)	Outcome	Results
13	Borup H et al.	2017	Systematic review: chronic obstructive pulmonary disease and construction workers.)	Occup Med (Lond). 2017 Apr 1;67(3):199-204.	-	-	818 deaths in the cohort (Overall mortality rate)	-	-
14	Dement J et al.	2015	A case-control study of airways obstructionamong construction workers.)	Am J Ind Med. 2015 Oct;58(10): 1083-97	834 cases and 1243 controls participating in a national medical screening program for older construction workers between 1997 and 2013.	Case-control study	Construction worker (Office workers)	-	-
15	Tüchsen F et al.	2012	Time trend in hospitalised chronic lower respiratory diseasesamong Danish building and construction workers,1981-2009: a cohort study.	BMJ Open. 2012 Nov 6;2(6).	Danish construction workers over three time periods (1981-1990, 1991-2000, 2001-2009).	Cohort study	-	-	-

Appendix Ⅴ. Literature review of occupational disease among construction workers_*Skin Disease*

No	Author	Year	Title	Journal	Participants	Study design	Exposure (comparison)	Outcome	Results
1	Stocks SJ et al.	2011	Occupation and work-related ill-health in UK construction workers.	Occup Med (Lond). 2011 Sep;61(6):407-15.	Constructionrelatedoccupationinthe UKfrom2002-2008	THOR (The Health and Occupation Reporting network) data	Employed in UK construction industry (All other employment sectors)	SRRs (Standadised incidennce rate ratios)	* By Industry (Age <65) -Contact dermatitis SRR 1.4 (1.2-1.6), Skin neoplasms SRR 4.2 (3.3-5.3), Benign keratosis (benign keratosis) SRR 4.8 (3.2-7.0), Basal cell carcinoma (basal cell carcinoma) SRR 3.7 (2.6- 5.3), Squamous cell carcinoma SRR 5.0 (2.5-10.0), Melanoma SRR 6.6 (3.5-12.3) * By occupation (age <65) -Contact dermatitis SRR 2.0 (1.8-2.3), Skin dysplasia SRR 3.9 (3.1-4.9), Benign keratosis SRR 4.7 (3.1-6.9), Basal cell carcinoma SRR 3.6 (2.5-5.2), Squamous cell carcinoma SRR 4.8 (2.4-9.6), Melanoma SRR 6.5 (3.5-12.2)
2	Stocks SJ et al.	2010	The incidence of medically reported work-related ill health in the UK construction industry.	Occup Environ Med. 2010 Aug;67(8):574-6.	Employed in UK construction industry	THOR (The Health and Occupation Reporting network) data	Employed in construction trade (All other employment sectors)	SRRs (Standadised incidennce rate ratios) of Lung cancer	* Contact dermatitis -Welder SRR 1.1 (0.7-1.7), Metal handling worker SRR 1.4 (1.1-1.7), Bricklayer and mason SRR 1.1 (0.8-1.6)), Construction manager SRR 1.4 (1.1-1.8), Other general labor SRR 1 .6 (1.1-2.3) * Skin cancer -Roofer SRR 6.3 (3.1-13.1), Construction manager SRR 6.3 (4.5-8.8), Painter SRR 2.1 (1.2-3.6), Other construction industry general labor SRR 6.6 (3.2-13.2), Skilled construction engineer SRR 3.2(2.3-4.5)

Appendix Ⅴ. Literature review of occupational disease among construction workers_*Skin Disease*

No	Author	Year	Title	Journal	Participants	Study design	Exposure (comparison)	Outcome	Results
3	Arndt V et al.	2005	Construction work and risk of occupational disability: a ten year follow up of 14,474 male workers.	Occup Environ Med. 2005 Aug;62(8): 559-66.	14,474 male workers from the construction industry in Germany aged 25-64 (heath examination 1986-1992)	Cohort study	Construction workers (n=95/14,474) (General workforce)	SIR(Standadised incidennce ratios)	*Skin disease SIR: 1.61(0.65-3.32)
4	Håkansson N et al.	2001	Occupational sunlight exposure and cancer incidence among Swedish construction workers.)	Epidemiology. 2001 Sep;12(5): 552-7.	323,860 men participating in an occupational health service program in the Swedish construction industry		Construction workers exposed to a lot of sunlight (Office workers such as managers)	RR (Relative Risk)	* Skin/melanoma related -Lip RR 1.8 (0.8-3.7) -Lower lip RR 1.7 (0.7-3.8) -Malignant melanoma of the skin RR 1.1 (0.8-1.6) -Malignant melanoma of the head, face and neck RR 2.0 (0.8-5.2) -Eye RR 3.4 (1.1-10.5)
5	Uter W et al.	2004	Contact allergy in construction workers: results of a multifactorial analysis.)	Ann Occup Hyg. 2004 Jan;48(1):21-7.	Between 1992 and 2000, 82,561 patients with contact dermatitis from the Said Dermatology Information Network (IVDK)		Construction worker (Office workers, faculty, waiters, service workers)	PR (Prevalence Ratio)	* Allergen -Construction worker PR 3.79 (3.18-4.51)

Appendix Ⅵ. Hazards controls in construction industry (referred by OSHA Fact sheet and HSE_FAQ_Health risk)

Hazards	Job types	Controls
Noise	Excavator Concrete finisher Welder etc.	· Eliminate noise during design · Substitute a less noisy process · Remove people from the vicinity of noisy work (Far from compressor and generators) · Select quite equipment (new muffles, new equipment) · Shield noise using plywood or plastic sheeting · Cut the time spend around loud noise · Wear protective equipment · Measure the noise on site and have hearing checked each year
Whole body vibration	Excavator etc.	· Adjust the driver weight setting in their suspension seats, where it is available, to minimize vibration and avoid the seat suspension 'bottoming out' when travelling over rough ground · Adjust the seat position and controls correctly, where adjustable, to provide good lines of sight, adequate support and ease of reach for and hand controls · Adjust the vehicle speed to suit the ground conditions to avoid excessive bumping and jolting · Steer, brake, accelerate, shift gears and operate attached equipment, such as excavator buckets, smoothly · Follow worksite routes to avoid travelling over rough, uneven or poor surface · Select vehicles and machines with the appropriate size, power and capacity for the work and the ground conditions

Appendix Ⅵ. Hazards controls in construction industry (referred by OSHA Fact sheet and HSE_FAQ_Health risk)

Hazards	Job types	Controls
Solvent	Painter Road paver etc.	· Read the labels and the MSDS (material safety data sheet) for each solvent you will use. · Never heat solvents by welding or torch cutting near solvent vapors or on surfaces that have solvent residue · Replace solvents when you can. - Use water-based strippers and lacquers(with less solvent). · Don't get solvents on your skin. · Wash your hands before you smoke, eat, or drink. · Try not to breathe solvents. · Work with solvents only in well-ventilated areas.
Crystalline silica	Excavator Concrete finisher Welder etc.	· Wet down dry materials - Use equipment with water sprays Or a HEPA vacuum · Use local exhaust ventilation · For abrasive blasting, replace silica sand with safer materials or use safer methods. · When doing abrasive blasting, you need to use a abrasive blasting respirator · When drilling in rock that may contain silica, you may need a respirator · Do not eat, drink, or smoke near silica · Change out of your work clothes before you go home

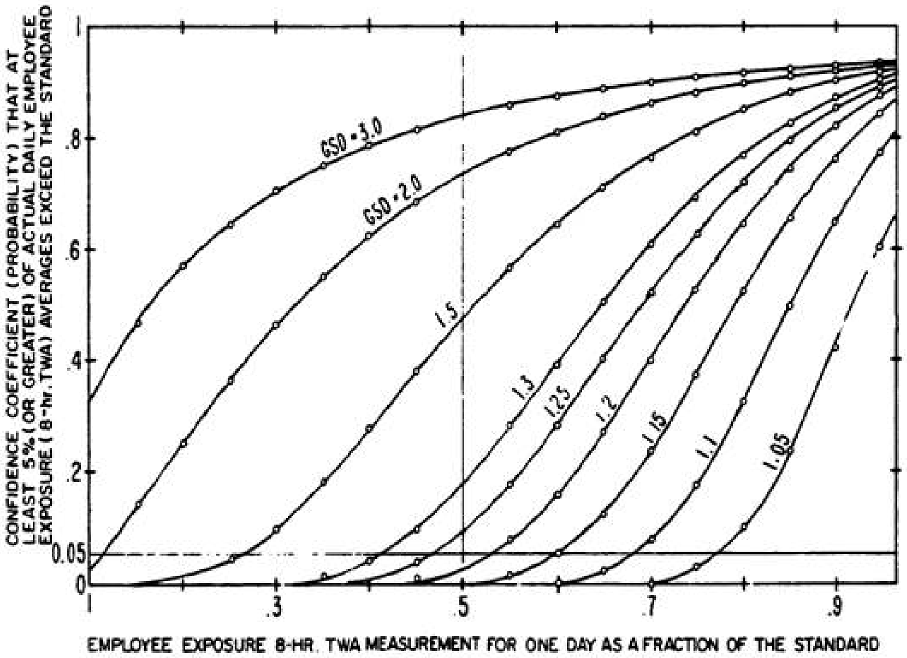
Appendix Ⅵ. Hazards controls in construction industry (referred by OSHA Fact sheet and HSE_FAQ_Health risk)

Hazards	Job types	Controls
Diesel engine exhaust	Excavator Road paver etc.	· Modify the operation to eliminate exhaust emission inside the workplace · Substitute diesel fuel with a safer or alternative technology where practicable, (eg. compressed natural gas, battery powered vehicles) · Use of lower emission or more fuel-efficient engines where possible, eg. higher engine injection pressure to reduce particulates, fitting exhaust gas recirculation system to reduce gaseous oxide emissions · Use cleaner fuels such as low sulfur diesel fuels · Enclosing the exhaust tailpipe from which DEEs are emitted, for example by using a fixed flexible hose with tailpipe exhaust system · Use of diesel exhaust gas 'after-treatment' systems such as catalytic converters to oxides organic substances and gases, and catalyzed and non-catalyzed particulate traps to remove particulate matter
Welding fume & Metals	Welder etc.	· Remove all paint and solvents before welding or torch cutting. Make sure all residues are removed · Use the safest welding method for the job. Stick welding makes much less fume than flux core welding · Use welding rods that produce a low fume. 90% of the fume can come from the rod. - Welding guns that extract fumes can capture 95% of the fume. · Use cleaner fuels such as low sulfur diesel fuels · Use local-exhaust ventilation to remove fumes and gases at their source in still air. · Use air blowers to blow fumes away from you when you are outdoors and it's windy. · Keep your face far from the welding plume

Appendix Ⅵ. Hazards controls in construction industry (referred by OSHA Fact sheet and HSE_FAQ_Health risk)

Hazards	Job types	Controls
Dust	Excavator Concrete finisher Welder etc.	· Use the right size of building material so less cutting or preparation is needed · Use a less powerful tool (block splitter can be used instead of a cut-off saw) · Two main ways of doing this which both give very good results - Water: water damps down dust clouds (However, it needs to be correctely. This means enough water for the whole time that the work is being done. Just wetting an area of ground before cutting does not work) - Vacuum extraction: specifically designed tools can be fitted with an industrial vacuum unit that sucks the dust away as it being created and stores it until emptied.
Ultra violet ray	Welder etc.	· UV-blocking safety eyewear (goggles, spectacles, face shields, welding shields, etc.) with side-shields where applicable · Long-sleeved, closely-woven clothing that covers as much the body as practicable · Sun-screen with a sun-protection factor (SPF) of 30 or higher and effective against UV-A and UV-B on all exposed skin
Epoxy, Isocyanate	Painter etc.	· Ventilation should be the principal method for minimizing isocyanate exposure · Worker isolation and use of personal protective equipment such as respirators and personal protective clothing to prevent dermal exposure may also necessary · Early recognition of sensitization and prompt and strict elimination of exposure is essential.

Appendix Ⅶ. Occupational Exposure Sampling Steratery Manual; Employee overexposure risk curves for one 8-hour TWA exposure measurement (NIOSH, 1977)



국 문 초 록

건설업은 노동의존도가 매우 높은 산업으로, 건설업 근로자는 작업과정 중 다양한 유해인자에 복합적으로 노출되는 것으로 알려져 있다. 그러나, 작업장 이동이 많고, 단위작업 장소에서의 작업시간이 짧으며, 작업환경이 지속적으로 변화하는 특성으로 인해 노출되는 유해인자의 농도수준 및 특성에 대해서는 잘 알려져 있지 못하다. 이번 연구는 건설업 근로자의 직종별 노출 유해인자를 조사하고, 직업성 암 등 건강장해 발생 위험이 높은 직종(지하 굴착공, 콘크리트 마감공, 방수도장공, 용접공, 아스팔트 도로포장공)을 우선대상으로 선정하여 발암성 물질을 중심으로 유해인자 노출농도 수준 및 농도에 영향을 주는 환경변수 등을 평가하였다.

먼저, 탑다운 공법을 적용한 주상복합 건축물 신축현장 4개소의 지하 굴착작업 중 발생하는 원소탄소 (elemental carbon, EC), 다환방향족탄화수소 (polycyclic aromatic hydrocarbons, PAHs), 호흡성 산화규소 결정체 (respirable crystalline silica, RCS)의 노출농도 수준을 살펴보았다. EC 농도는 권고기준인 20 ㎍/㎥을 초과하는 시료가 전체의 약 50 %를 차지하였다. RCS의 기하평균(geometric mean, GM)농도는 노출기준인 0.05 ㎎/㎥의 1.5배를 초과하였다. 주요 환경변수로 암석지반, 높은 장비 밀집도, 발파작업, 환기조건이 나쁠수록 EC 및 RCS 농도수준이 높은 것을 알 수 있었다. 특히, 작업환경개선이 가장 우선 적용되어야할 대상은 상부가 밀폐된 경암 지반의 현장이었다. 지하 굴착작업장에서 디젤엔진 배출물 및 산화규소 노출을 최소화하기 위한 노력으로 작업장 상부를 최대한 개방하여 충분한 환기를 실시하고, 살수를 통한 습식작업환경 조성, 노후 차량의 교체, 차량의 정기 점검 및 유지 보수, 및 저유황유 사용 등의 개선조치가 필요하다.

아파트 건설현장 8개소의 콘크리트 마감작업(할석, 그라인딩, 미장작업)에 대한 RCS 노출 농도를 평가하였다. RCS의 GM 농도는 콘크리트

그라인딩 작업에서 2.06 ㎎/㎥, 할석작업에서 0.12 ㎎/㎥로 노출기준인 0.05 ㎎/㎥의 각 40배 및 2배를 초과하였다. 콘크리트 그라인딩 작업 중 RCS 농도는 계단실 (4.18 ㎎/㎥), 세대내부 (2.76 ㎎/㎥), 지하작업장 (1.30 ㎎/㎥) 등 작업 공간 체적이 작을수록 농도수준이 높음을 알 수 있었다. 작업환경개선이 가장 우선 적용되어야할 대상은 작업공간이 작은 장소에서의 콘크리트 연마작업이었다. 건설현장 콘크리트 마감 작업 중에서 RCS 노출을 저감하기 위해서는 환기캡을 적용한 국소배기장치의 사용, 습식작업 등의 작업환경개선이 시급하며, 공학적 개선과 함께 호흡보호구의 철저한 지급・착용 및 밀착도 검사, 주기적인 건강검진 모니터링이 필요하다.

건설현장 도장작업자에 대한 휘발성 유기화합물(volatile organic compounds, VOCs) 노출수준을 살펴보기 위해 8개 건설현장에서 우레탄 방수작업에 대해 평가하였다. VOCs의 혼합물질 노출지수(exposure index, EI; 노출기준=1)의 GM은 국내 노출기준(Korea occupational exposure limits, KOEL)의 약 78%수준이었으며, KOEL을 초과하는 시료가 전체시료의 약 38.6%로 작업환경관리가 요구되는 수준이다. 더욱이, EI를 미국 ACGIH TLVs에 따라 산출하면, EI의 GM이 1.84로 KOEL의 약 2배 수준으로 매우 높았다. 혼합물질 평가에 가장 큰 영향을 미치는 물질은 톨루엔이었다. 작업별로는 실내 우레탄 프라이머 도포작업에서 노출농도가 가장 높았다. 건설현장 도장작업자의 건강관리를 위해 도료 구성성분 중 발암성 물질과 생식독성물질은 최대한 유해성이 낮은 물질로 대체하고, 농도수준에 따라 적절한 보호계수를 갖는 개인보호구의 지급 및 착용 및 지속적인 노출평가와 건강검진 실시결과에 대한 사후관리가 필요하다. 또한, 실내 작업의 경우는 환기장치를 가동하고 작업을 진행하여 유기화합물 노출을 최소화 하여야 한다.

건설현장 일반건축물 배관용접공, 화학플랜트 배관용접공, 철골용접공, 소각플랜트 보일러 제작 용접공, 금속마감용접공을 대상으로 용접흄 및

금속류에 대한 노출농도(GM) 수준을 살펴보았다. 용접흄의 농도는 일반건축물 배관공 (4.75 ㎎/㎥)> 철골용접공 (3.77 ㎎/㎥) > 보일러제작용접공 (1.38 ㎎/㎥)> 금속마감용접공 (0.78 ㎎/㎥) > 화학플랜트 배관용접공 (0.71 ㎎/㎥) 순으로 높았다. 용접기법에 따른 용접흄 농도는 CO_2용접 (2.08 ㎎/㎥) > 피복아크용접 (1.54 ㎎/㎥) > TIG용접 (0.70 ㎎/㎥) 순으로 높았고, 동일한 직종의 일반건축물 배관용접작업에서 지하공간 (7.75 ㎎/㎥)과 지상층 실내공간 (2.15 ㎎/㎥)의 용접흄 농도차이는 약 3.6배로 더욱 커서 작업장 환기조건이 용접흄 농도에 중요한 환경변수 임을 알 수 있었다. 용접작업 위험도가 높은 일반건축물의 배관용접과 철골용접 작업, 지하공간에서의 용접작업, CO_2 용접작업 등을 수행할 시에는 환기장치 사용과 호흡용 보호구 착용 등 철저한 작업환경관리와 작업 시 아크까지 일정거리 유지, 적정 용접전류 선택 등 용접흄 발생을 최소화할 수 있는 근로자 안전보건교육이 필요함을 알 수 있었다.

아스팔트 도로포장을 실시하는 건설현장 3개소에서 아스팔트 흄(벤젠추출법) 및 다환방향족탄화수소(PAHs) 농도를 직종별로 살펴보았다. 아스팔트 흄(벤젠추출법) 농도의 직종별 차이를 살펴보면, 포장특공 (42.32 ㎍/㎥), 포설장비 운전원 (41.57 ㎍/㎥), 머캐덤 운전원 (31.9 ㎍/㎥), 타이어 운전원 (30.31 ㎍/㎥) 순으로 높았다. 아스팔트 흄은 노출기준 500 ㎍/㎥의 약 10% 수준으로 매우 낮았으나, PAHs의 경우, 대기환경 농도와 비교하면 수백배 높은 농도수준이었으며, 도료, 타르 제조업 등 타 업종과 비교하여 총 PAHs 농도는 낮았으나, 세부물질 중 Benzo(a)pyrene 농도가 상대적으로 높은 특성이 있었다. 또한 아스팔트 도로포장 작업의 경우 주변 건물 및 풍속 등 환경변수에 따른 농도변이가 매우 큰 특성이 있으므로 다양한 작업현장을 대상으로 추가적인 노출평가 연구가 요구된다.

이번 연구를 통해 그동안 잘 알려져 있지 못한 건설업 근로자의 유해인자 및 노출농도 수준을 확인할 수 있었다. 직종별 노출평가 결과에서 대부분의 작업이 노출기준을 초과하여 직업성 암 등 건강장해 발생 위험

이 높은 수준임을 확인할 수 있었다. 베이시안(Bayesian) 통계기법을 활용한 평가자료의 95% 상위값이 노출기준을 초과할 확률을 살펴보면, 지하굴착공의 윈소탄소 및 산화규소(결정체), 콘크리트 할석, 그라인딩공의 산화규소(결정체), 도장공의 휘발성 유기화합물, 일반건축물 배관용접공 및 철골용접공의 용접흄 농도는 약 5% 이상의 작업자는 노출기준을 초과할 우려가 있음으로 평가되어 작업환경개선이 요구되었다. 또한, 건설현장의 특성상 평가그룹별 농도의 변이수준이 높음을 확인하였으며, 향후 작업환경측정 시 변이를 고려한 적정 시료수, 반복측정 및 유사노출그룹 선정과 추정 상한치 등을 통한 위험수준 평가 적용이 필요함을 알 수 있었다. 평가농도에 영향을 미치는 주요 환경변수는 작업장의 환기조건, 건축재료, 작업방식 등임을 확인하였으며, 직종별 특성에 맞는 지속적인 작업환경개선 노력과 설계단계에서부터 유해인자 노출을 감소시킬 수 있는 공법의 도입 등이 필요하다. 또한, 향후 건설업 특화된 작업환경측정 및 건강관리제도의 개선과 지속적인 노출평가 연구가 요구된다. 이번 연구결과는 건설노동자의 업무상 질병 역학조사 시, 노출농도 예측을 위한 자료로 활용가능하며, 연구결과를 통해 도출된 농도에 영향을 주는 주요 환경변수 및 개선방안에 따라 건설현장 작업환경개선에도 기여할 수 있을 것으로 기대된다.

Key words: 건설업 근로자, 지하굴착작업자, 콘크리트마감 작업자, 도장공, 용접공

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