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Original Article

국내 업종별 결정형 유리규산 노출 평가

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Evaluation of Crystalline Silica Exposure Level by Industries in Korea

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ABSTRACT

Objectives: The major aim of this study is to construct the database of retrospective exposure assessment for crystalline silica through reviews of literatures in South Korea.

Methods: Airborne concentrations of crystalline silica were collected using an academic information search engine, Research Information Service System(RISS), operated by the Korea Education & Research Information Service(KERIS). The key words used for the literature search were 'silica', 'crystalline silica', 'cristobalite', 'quartz' and 'tridymite'. A total number of 18 published documents with the information of crystalline silica level in air or bulk samples were selected and used to estimate retrospective exposures to crystalline silica. Weighted arithmetic mean(WAM) calculated across studies was summarized by industry type. Industries were classified according to Korea Standard Industrial Classification(KSIC) using information provided in the literature.

Results: A total of 2,131 individual air sampling data measured from 1987 to 2012 were compiled. Compiled individual measurement data consisted of 827 respirable crystalline silica (RCS), 31 total crystalline silica(TCS), 24 crystalline silica(CS), 778 respirable dust(RD) and 471 total dust(TD). Most of RCS measurements(68.9%) were collected from 'cast of metals(KSIC 243)'. Comparing industry types, 'mining coal and lignite(KISC 051)' showed the highest WAM concentration of RCS, 0.14 ㎎/㎥, followed by 0.11 ㎎/㎥ of 'manufacture of other non-metallic mineral products(KSIC 239)', 0.108 ㎎/㎥ of 'manufacture of ceramic ware(KSIC 232)', 0.098 ㎎/㎥ of 'heavy construction(KSIC 412)' and 0.062 ㎎/㎥ of 'cast of metals(KSIC 243)'. In terms of crystalline silica contents in airborne dust, 'manufacture of other non-metallic mineral products(KSIC 239)' showed the highest value of 7.3%(wt/wt), followed by 6.8% of 'manufacture of ceramic ware(KSIC 232)', 5.8% of 'mining of iron ores(KSIC 061)', 4.9% of 'cast of metals(KSIC 243)' and 4.5% of 'heavy construction(KSIC 412)'. WAM concentrations of RCS had no consistent trends over time from 1994 (0.26 ㎎/㎥) to 2012 (0.12 ㎎/㎥).

Conclusion: The data set related RCS exposure level by industries can be used to determine not only the possibility of retrospective exposure to RCS, but also to evaluate the level of quantitative retrospective exposure to RCS.

Key words: crystalline silica, Korea Standard Industrial Classification, retrospective exposure estimation

I. 서 론

직업성폐질환연구소에서 1999년부터 2005년까지 역학조사를 통해 직업성 폐암으로 판단된 사례 분석 결과에서 업무관련성이 높다고 판단된 직업성 폐암 53례 중 결정형 유리규산으로 인한 폐암 사례가 14례로 석면, 다핵방향족탄화수소, 6가 크롬 다음으로 높은 비율을 차지하고 있다(Lim et al., 2010).

보통 유리규산은 비결정형, 결정형과 규산염으로 나눌 수 있으며 결정형 유리규산의 일반적인 형태로는 석영(quartz)과 트리디마이트(tridymite), 크리스토발라이트(cristobalite)가 있다. 산업분야에서 석영은

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유리제조, 주물, 연마제, 수압파쇄작업 등에서 사용되며 화강암 등이 포함된 채광작업에서 노출이 이루어진다. 석영의 제조는 주물사 건조납품, 석영유리 제조 등에서 나타나 국내에서는 200여개 사업장 5만여명의 근로자가 노출되며 연간 300만톤 이상 사용되고 있다. 이는 주물사를 사용하는 업종이다. 또한 농업, 도로건설, 보수 등에서도 노출된다. 발생공정으로는 블라스팅작업, 요업, 유리제조, 주물, 토사석 채취, 화강암 석수공, 내화, 분쇄 등이다(KOSHA 2007).

화학물질 유통·사용 실태조사 결과에 의하면 우리나라에서 결정형 유리규산을 제조 또는 사용하고 있는 사업장에 대한 분포를 조사한 결과 결정형 유리규산을 사용하고 있는 사업장 수는 215개 이고, 총 근로자는 47,725명, 취급근로자는 1,905명(1~696명), 사용 취급량은 2,960,469,661 kg/년(1~283,240,000 kg/년)이었다. 결정형 유리규산을 제조하는 사업장수는 총 6개소, 총 근로자수는 190명(6~73명), 취급 근로자수는 74명(1~58명), 취급 량은 437,624,000 kg/년(24,000~363,000,000 kg/년)이었다(KOSHA, 2007). 제조하는 사업장 수는 적지만 사용하는 사업장이 많은 것을 알 수 있다.

과거 우리나라 유해물질 허용농도에서는 유리규산의 함유량에 따라 총 분진을 제 1,2,3종 분진으로 분류하여 허용농도를 달리 정하였으며, 호흡성 분진으로서 결정형 유리규산의 경우 석영 0.01 ㎎/㎥, 트리디마이트와 크리스토발라이트를 0.05 ㎎/㎥로 따로 규정했었으나 개정되어 현재 3종류 모두 결정형 유리규산으로 포함되어 노출기준 0.05 ㎎/㎥으로 정하고 있다(MoEL, 2016). 미국정부산업위생전문가협의회(American Conference of Governmental Industrial Hygienist, ACGIH)는 0.025 ㎎/㎥로 정하고 있다(ACGIH, 2015).

결정형 유리규산은 그 자체로 진폐증을 발생시킬 뿐 아니라, 석탄 분진, 활석, 규조토와 같이 혼합되면 분진의 독성은 더욱 증가된다(KOSHA, 2013). 국제암 연구기구(International Agency for Research on Cancer, IARC)에서는 결정형 유리규산에 호흡성 입자(respirable fraction)로 노출 시 인체에 폐암 발병의 충분한 근거가 있다고 하여 인체발암물질(Group1)로 구분하고 있다(IARC, 1997).

국내에서는 개별 업종에 따른 결정형 유리규산 노출값과 그에 따른 건강 유해성을 연구한 학술 논문들은 있으나, 근로자의 과거 노출력 판단과 업무관련성 평가를 할 수 있는 업종별 시대별 노출수준에 대한 데이터베이스는 없는 실정이다. 이에 본 연구에서 발암 물질인 결정형 유리규산에 대한 노출수준 및 원료 및 공기 중 먼지 중 결정형 유리규산 함유량에 대해 2015년까지 발표된 국내 문헌을 수집 분석하여 데이터베이스를 구축하고자 하였다.

Ⅱ. 연구방법

1. 문헌 자료 수집

결정형 유리규산과 관련되어 2015년 9월까지 국내에서 발표된 연구논문, 학위논문, 보고서 자료를 수집하였다. 자료 검색은 국내 학술자료 검색 사이트인 디비피아(DBpia), 한국학술정보(KISS), 학술연구정보서비스(RISS)를 활용하여 '결정형 유리규산', '유리규산', '석영' 그리고 '실리카'를 검색어로 검색하였다.

학술논문으로 발표되지는 않았으나 결정형 유리규산이 폐암 유발인자이기 때문에 직업성폐질환 연구소에서 2014년에 발표한 '업무상질병사례집(2007-2012)'도 분석 대상에 포함하였다. 또한 한국산업안전보건공단에서 수행한 연구보고서 자료도 검색 대상에 포함하여 관련 자료를 수집하였다.

수집된 자료 중 결정형 유리규산의 함유량이 있거나, 결정형 유리규산이 발생 가능한 업종에서 측정된 공기 중 총 분진, 호흡성 분진, 결정형 실리카에 대한 정량적 노출농도가 제시된 자료를 분석 대상에 포함 하였다.

최종 분석에 활용된 자료는 국내 전문 학술지에 발표된 논문 9편, 직업성폐질환연구소 보고서 1편, 한국산업안전보건공단 보고서 3편, 학술대회 발표자료 5편 등 총 18편이었다.

2. 자료 입력

분석 대상 자료 18편에 대해 결정형 실리카의 함유량 분석 결과와 공기 중 노출 농도를 나누어 정리하였다. 각 자료 입력에 활용된 변수는 조사년도, 업종, 공정, 직종, 시료채취 방법, 시료분석 방법, 채취대상 물질, 분석대상 항목이었으며, 결과 값은 시료 수(N), 최소값(Min), 최대값(Max), 기하평균(GM), 기하표준편차(GSD),

산술평균(AM), 표준편차(SD)를 모두 입력하였다.

자료에 제시된 업종명을 통계청 고시 제2007-53호의 제9차 한국표준산업분류(KSIC)에 기준하여 세세분류(5 digit)까지 표준 업종으로 재분류하여 입력하였다.

3. 자료 처리

자료 처리 대상인 논문 중 일부는 GM, GSD로 제시되어 있었고, 일부는 최소-최대값만 제시된 경우가 있었다. 또한 일부 논문에서는 산술평균값만 제시된 경우도 있다. 따라서 전체 자료의 변수별 비교를 위해 모두 산술평균으로 변환(AM_T)하였다.

기하평균으로 보고된 농도는 아래의 (식 1)을 이용하여 산술평균으로 변환하였다.

$$AM_T = GM\exp[1/2(\ln(GSD))^2] \quad (1)$$

농도가 최소-최대값의 범위로 보고된 경우 범위에 근거하여 아래 (식 2)에 대입 한 후 산술평균을 계산하였다. 계산식은 최소값과 최대값을 대수로 변환하여 그 중간값(mid-point)을 구하고($\widehat{\mu_L}$), 대수로 변환한 최소값과 최대값의 차이를 4로 나눈 값($\widehat{\sigma_L}$)을 구하였다.

$$AM_T = \exp[\ \widehat{\mu_L} + 1/2\,\widehat{\sigma_L^2}\ ] \quad (2)$$

입력 대상 값 중 최소값이 ND(not detected)로 제시된 경우 통계 분석을 위해 0으로 입력하였고, 시료수가 제시되지 않고 평균값만 제시된 경우 시료 수는 1로 입력하였다.

업종별 혹은 조사년도에 따른 비교 시 논문마다 측정한 시료 수가 차이가 있기 때문에 시료수의 차이에 따른 산술평균을 보정하기 위해 시료수에 대한 가중산술평균(Weighted Arithmetic Mean, 이하 WAM이라 함)을 구하였다. 가중산술평균을 구할 때 시료의 수를 정확히 알 수 없는 데이터 값의 가중치는 1로 간주하여 계산하였다.

$$WAM = (N_1\times AM_1+N_2\times AM_2+ \cdots +N_i\times AM_i)/N_t \quad (3)$$

여기서 N_i=i번째 자료의 시료수, AM_i=i번째 자료의 산술평균, N_t=총 시료수이다.

Ⅲ. 연구결과

1. 연구대상 문헌의 특성

국내 학술지, 연구보고서, 포스터 그리고 폐질환연구소의 업무상 질병 사례집에서 얻은 모든 작업환경측정을 실시한 결정형 유리규산, 총 분진, 호흡성 분진의 농도 및 함량에 대한 데이터베이스를 정리하여 분석하였다. 데이터베이스의 세부 자료는 Appendix 1~6에 제시하였다. 데이터베이스를 구축하기 위해 참고하여 연구 했던 최종 참고문헌들의 정보는 Table 1에 나타내었다.

총 18편의 연구자료 중 다양한 업종을 대상으로 결정형 유리규산에 대해 연구가 수행된 자료 중 2000년 이전 연구자료는 1997년에 주물, 콘크리트, 벽돌, 유리, 분쇄, 요업 등의 제조업을 대상으로 김현욱 등이 실시한 연구(Kim et al., 1998, Kim et al., 1999)가 있었다. 2000년 이후 자료 중에는 산업안전보건연구원에서 수행한 '화학물질 유통·사용 실태조사 결과보고서' 중 유리규산 편으로 연구된 자료(KOSHA, 2007)와 직업성폐질환 연구소에서 2014년에 발표한 '업무상질병사례집(2007-2012)'이 있다(KWCWS, 2014). 그러나 이 두 자료는 학술연구논문처럼 peer-review된 연군논문이 아니고 보고서라는 특성이 있다.

특히 산업안전보건연구원에서 수행된 유리규산에 대한 유통·사용 실태 보고서에서는 16개의 KSIC 소분류에 해당되는 다양한 업종의 자료가 수록되어 있으나, 결정형 실리카에 대한 노출평가 자료가 모두 산업안전보건법 제42조에 의해 2004년에 실시된 작업환경측정 자료이기 때문에 대부분 총분진(TD) 자료로 제시되어 있어 결정형 실리카의 정확한 농도를 예측하기 어려운 한계가 있다.

직업성 폐질환 연구소에서 펴낸 보고서 자료는 직업성폐질환연구소에서 역학조사를 수행하며 직접 현장 조사와 시료 분석을 하여 제시한 결과들이 제시되어 있어 보고서 자료이지만 자료의 정확도가 높다고 판단된다.

자료의 조사 시기별로 보면 1980년대에는 석탄광업에 대한 자료만 보고되고 있고, 1990년대와 2000년대에 걸쳐 모두 자료가 보고되고 있는 업종은 주

Table 1. Characteristics of 18 references with quantitative data of crystalline silica in Korea

Reference	Source	Year	Industry(KSIC-3digit)	Sample type	Analyte	Method
Yoon & Lee, 1988	Article	1987	Mining of coal and lignite	Bulk/Air	CSC/RD	FTIR, Weighing
Lee & Lee, 1989	Article	1989	Mining of coal and lignite	Bulk/Air	CSC/RD	FTIR, Weighing
Oh et al., 1994	Article	1994	Manufacture of ceramic ware	Bulk/Air	CSC/RCS, TCS, RD, TD	FTIR, Weighing
Phee et al., 1997	Article	1996	Cast of metals	Bulk/Air	CSC/RCS, RD, TD	FTIR, Weighing
Kim et al., 1998	Article	1997	Cast of metals	Bulk/Air	CSC/RCS, TD, RD	FTIR, XRD, Weighing
Kim et al., 1999	Article	1997	Manufacture of cement, Lime and plaster and its products, Manufacture of ceramic ware, Manufacture of coke and briquettes, Manufacture of glass and glass products Manufacture of other non-metallic mineral products	Bulk/Air	CSC/RCS, RD	FTIR, XRD, Weighing
Shin et al., 2002	Article	2000	Mining of coal and lignite	Bulk/Air	CSC/RCS, TSC, RD, TD	FTIR, Weighing
Choi et al., 2000	Report	2000	Mining of iron ores, Quarrying of stone, sand and gravel	Bulk/Air	CSC/TCS, RCS, TD, RD	FTIR, Weighing
Yoo et al., 2003	Report	2001	Heavy construction	Bulk/Air	CSC/RCS, RD, TD	FTIR, Weighing
Park et al., 2003	Article	2002	Cast of metals	Bulk/Air	CSC/RCS, RD	FTIR, Weighing
KOSHA, 2007	Report	2004	Cast of metals, Manufacture of basic chemicals, Manufacture of basic iron and steel, Manufacture of basic precious and non-ferrous metals, Manufacture of cement, Lime and plaster and its products, Manufacture of ceramic ware, Manufacture of glass and glass products, Manufacture of other chemical products, Manufacture of other metal products; metal working service activities, Manufacture of other non-metallic mineral products, Manufacture of parts and accessories for motor vehicles and engines, Manufacture of plastic products, Manufacture of precious metals and ornamentations, Manufacture of rubber products, Manufacture of structural metal products, Tanks, Reservoirs and steam generators	Air	CS, TD	Weighing
Kim et al., 2008a	Abstract	2008	Manufacture of cement, Lime and plaster and its products	Bulk	CSC	XRD
Kim et al., 2008b	Abstract	2008	Manufacture of basic iron and steel	Air	RCS	FTIR
Kim et al., 2009	Abstract	2009	Manufacture of cement, Lime and plaster and its products	Bulk	CSC	XRD
Kim et al., 2010	Abstract	2010	Manufacture of ceramic ware	Bulk/Air	CSC/RCS, RD	XRD, Weighing
Kim et al., 2012	Abstract	2008-2012	Manufacture of other non-metallic mineral products	Air	RCS	XRD
Kim et al., 2014	Article	2012	Manufacture of other non-metallic mineral products	Air	RCS, RD	FTIR
KWCWS, 2014	Report	2006-2012	Cast of metals, Farming of animals, Manufacture of ceramic ware, Manufacture of other chemical products, Manufacture of other non-metallic mineral products, Transit and ground passenger transportation, Farming of animals, Heavy construction, Manufacture of cement, lime and plaster and its products, Quarrying of stone, Sand and gravel, Site preparation and special trade construction for civil engineering and buildings	Bulk/Air	CSC/RCS, TD, RD	FTIR, XRD, Weighing

Note: CSC;crystalline silica content, RCS;respirable crystalline silica, TCS;total crystalline silica, RD;respirable dust, TD;total dust, CS;crystalline silica

물사업장이었다. 따라서 1990년대부터 최근까지 노출 시기별 결정형 실리카의 농도 평가는 주물 사업장을 대상으로 제한적으로 가능하다.

결정형 실리카의 분석 방법으로 보면 1980년대와 1990년대는 주로 FTIR 방법에 의해 실시되었으며, 최근에는 NIOSH 공정시험법인 XRD 방법에 의해 제시되고 있다. 본 논문에서는 업종별, 시기별 결정형 실리카의 농도를 비교할 때 시료수의 제한이 있기 때문에 FTIR과 XRD 분석 결과를 구분하지 않고 사용하였다.

2. 업종별 결정형 유리규산 농도와 함량

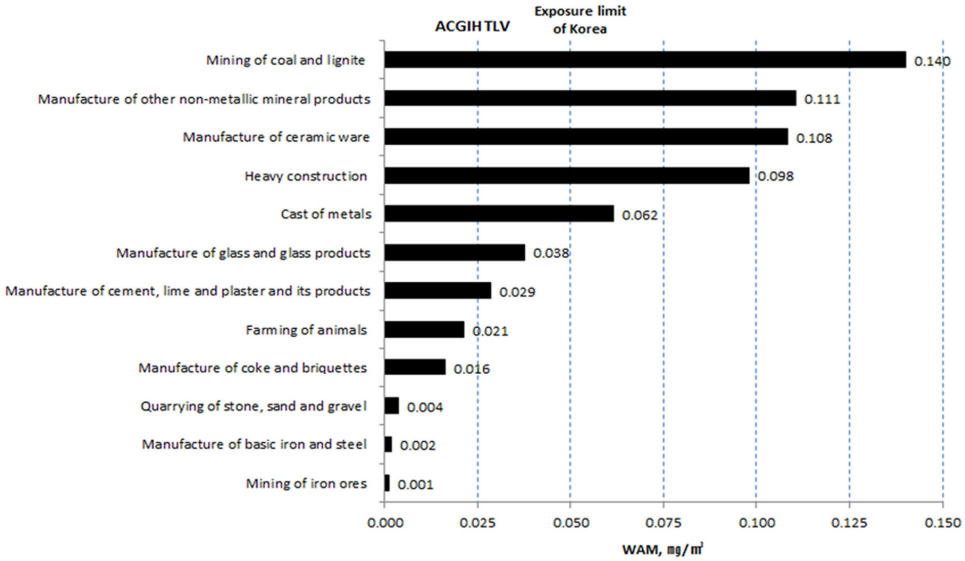
1) 업종별 농도 비교

총 분진, 호흡성 분진, 총 결정형 유리규산, 호흡성 결정형 유리규산, 결정형 유리규산 농도를 시료 수 가중산술평균으로 환산하여 통계청의 표준산업분류의 소분류 업종 별로 분석하였다. 모든 업종을 비교해 보았을 때 평균은 총 분진이 19.37 ㎎/㎥, 호흡성 분진 5.61 ㎎/㎥, 총 결정형 유리규산 0.22 ㎎/㎥, 호흡성 결정형 유리규산 0.07 ㎎/㎥, 결정형 유리규산 0.13 ㎎/㎥ 이였다(Table 2).

Table 2. Weighted average mean concentration of total dust, respirable dust, total crystalline silica, respirable crystalline silica and crystalline silica by industries

Industry(KSIC 3-digit)	Total dust		Respirable dust		Total crystalline silica		Respirable crystalline silica		Crystalline silica	
	N	WAM*, ㎎/㎥	N	WAM, ㎎/㎥	N	WAM, ㎎/㎥	N	WAM, ㎎/㎥	N	WAM, ㎎/㎥
Cast of metals	86	2.43	269	1.18			570	0.062	3	0.07
Farming of animals	4	9.86					3	0.021		
Heavy construction	102	4.71	103	1.35			53	0.098		
Manufacture of basic chemicals	2	0.29								
Manufacture of basic iron and steel	5	1.21					2	0.002		
Manufacture of basic precious and non-ferrous metals	4	1.74								
Manufacture of cement, lime and plaster and its products	5	0.61	4	0.30			9	0.029		
Manufacture of ceramic ware	134	2.28	81	0.71	26	0.20	59	0.108	5	0.034
Manufacture of coke and briquettes			4	0.62			6	0.016		
Manufacture of glass and glass products	16	0.89	4	1.23			4	0.038		
Manufacture of other chemical products	2	1.54							4	0.004
Manufacture of other metal Products; metal working service activities	10	1.71								
Manufacture of other non-metallic mineral products	20	1.98	31	0.98			62	0.111	10	0.19
Manufacture of parts and accessories for motor vehicles and engines	4	1.15								
Manufacture of plastic products	4	0.64								
Manufacture of precious metals and or namentations	1	0.04								
Manufacture of rubber products	2	1.44								
Manufacture of structural metal products, tanks, reservoirs and steam generators	1	3.00								
Mining of coal and lignite	48	160.7	243	15.50	5	0.30	25	0.14		
Mining of Iron ores	3	1.11	14	0.80			9	0.001		
Quarrying of stone, sand and gravel	17	15.32	25	1.36			25	0.004	2	0.42
Site preparation and special trade construction for civil engineering and buildings	1	6.18								
Total	471	19.37	778	5.61	31	0.22	827	0.07	24	0.13

* WAM: weighted arithmetic mean



* WAM: weighted arithmetic mean

Figure 1. Comparison of respirable crystalline silica concentrations by industries

체내로 노출 될 경우 가장 유해한 영향을 끼치는 호흡성 결정형 유리규산이 높은 농도로 노출되는 업종은 석탄 광업에서 0.14 ㎎/㎥, 기타 비금속 광물제품 제조업에서 0.111 ㎎/㎥, 도자기 및 기타 요업 제품 제조업에서 0.108 ㎎/㎥, 토목건설업 0.098 ㎎/㎥ 그리고 금속 주조업에서 0.062 ㎎/㎥로 나타났다. 이 노출 수준은 우리나라 고용노동부의 호흡성 결정형 유리규산 노출기준 0.05 ㎎/㎥를 초과하는 수준이다. ACGIH에서 호흡성 결정형 유리규산 TLV 값은 우리나라 노출기준 보다 낮은 0.025 ㎎/㎥인데, 이를 초과하는 업종을 추가 해보면 유리 및 유리제품 제조업이 0.038 ㎎/㎥, 플라스틱 제품 제조업이 0.029 ㎎/㎥이다(Figure 1).

2) 업종별 함량 비교

공기 중 분진 시료와 벌크시료 중 결정형 유리규산 함량은 시료가중평균값으로 환산하여 Table 3에 나타냈다. 표준산업분류는 소분류로 분석 하였으며

Table 3. Weighted average mean contents of airborne dust and bulk by industries

Industry (KSIC 3-digit)	Airborne dust		Bulk	
	N	WAM,%	N	WAM,%
Cast of metals	311	4.85	80	8.55
Farming of animals	2	1.65	1	80
Heavy construction	52	4.53		
Manufacture of cement, lime and plaster and its products	6	3.67	11	0.311
Manufacture of ceramic ware	84	6.84	17	16.39
Manufacture of coke and briquettes	6	3.21		
Manufacture of glass and glass products	4	4.02		
Manufacture of other chemical products			4	5.74
Manufacture of other non-metallic mineral products	10	7.33	1	6
Mining of coal and lignite	191	3.32		
Mining of Iion ores	17	5.77		
Transit and ground passenger transportation			2	17.5
Total	683	4.70	116	9.57

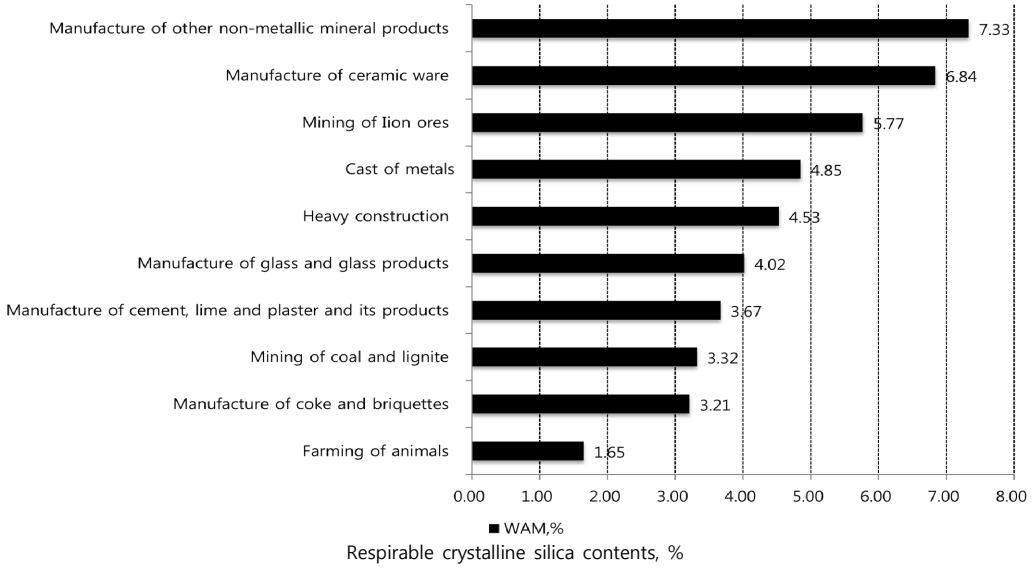


Figure 2. Comparison of respirable crystalline silica contents in airborne dust by industries

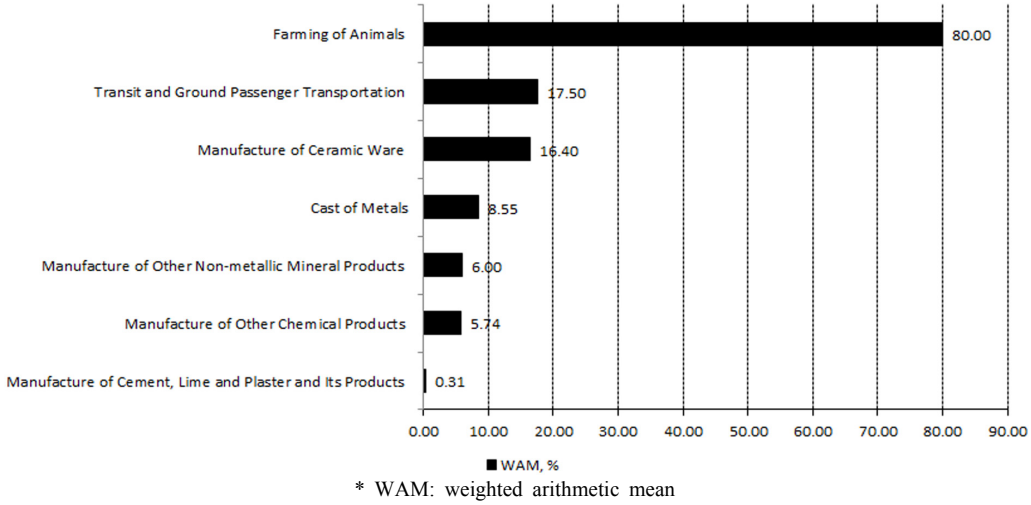


Figure 3. Comparison of respirable crystalline silica contents in bulk by industries

각각의 전체 평균은 공기 중 분진 시료 중 4.7%, 벌크시료 중에는 9.7%이다.

표준산업분류의 소분류를 기준으로 함량을 비교한 결과 공기 중 분진에서의 결정형 유리규산 함량이 가장 높은 업종은 기타 비금속 광물제품 제조업으로 7.33%이며 다음으로 도자기 및 기타 요업제품 제조업에서 6.84%이었다(Figure 2). 벌크시료 중 결정형 유리규산이 높은 업종은 축산업이 80%, 도시 정기 육상 여객 운송업과 도자기 및 기타 요업제품 제조업에서 각각 17.5%, 16.40%이다(Figure 3).

3) 호흡성 결정형 유리규산의 세세업종별 비교

인체에 영향을 끼치는 호흡성 결정형 유리규산의 통계청 표준산업분류에서의 세세분류에 따라 비교해 보았다(Figure 4). 호흡성 결정형 유리규산 농도에 대한 세세분류별 시료 수 가중평균으로 환산한 결과 전체 평균은 0.07 ㎎/㎥이었고, 가장 농도가 높은 업종은 위생용 도자기 제조업 0.269 ㎎/㎥, 석탄광업

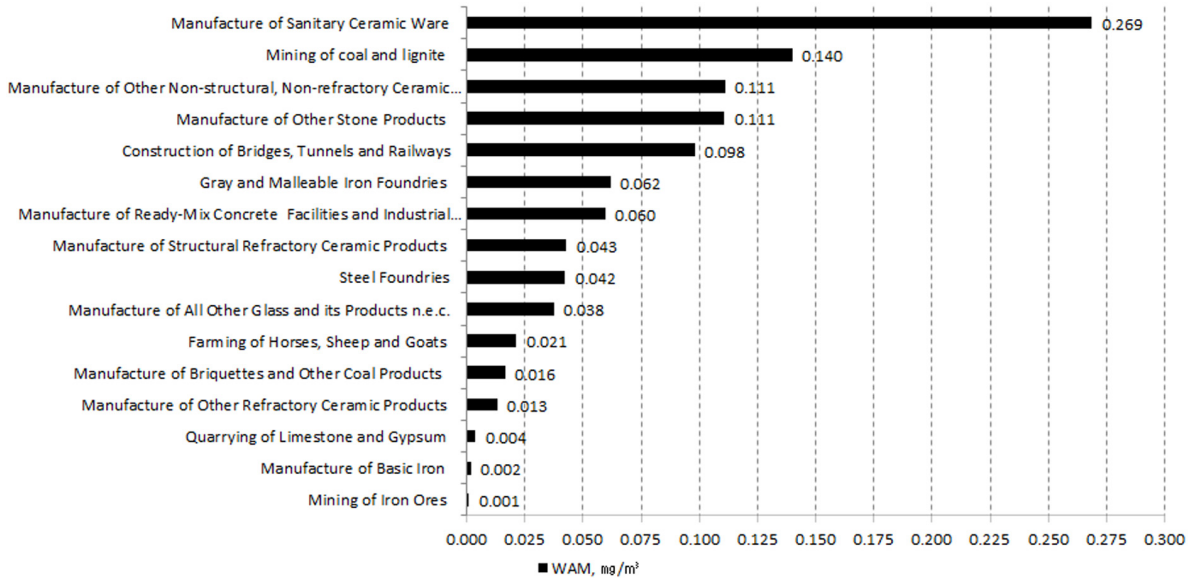


Figure 4. Comparison of respirable crystalline silica concentrations by industries((KSIC 5-digit)

0.14 ㎎/㎥, 기타 일반 도자기 제조업 및 기타 석제품 제조업에서 0.111 ㎎/㎥로 고용노동부 노출기준보다 높게 나타났다.

ACGIH –TLV 0.025 ㎎/㎥을 초과하는 업종은 교량, 터널 및 철도 건설업 0.098 ㎎/㎥, 선철주물 주조업 0.062 ㎎/㎥, 그 외 기타 유리제품 제조업 0.038 ㎎/㎥, 레미콘 제조업 0.06 ㎎/㎥, 구조용 정형 내화제품 제조업 0.043 ㎎/㎥, 강주물주조업 0.042 ㎎/㎥이었다.

3. 연도별 결정형 유리규산의 노출농도 현황

공기 중 결정형 유리규산 농도에서 연도별로 측정되었던 현황을 시료 수 가중평균농도로 분석했다. 분석물질의 선정은 작업자에게 유해한 영향을 줄 수 있는 결정형 유리규산, 호흡성 결정형 유리규산, 총 결정

Table 4. Weighted average mean concentration of total crystalline silica, respirable crystalline silica and crystalline silica by year

	Crystalline silica		Respirable crystalline silica		Total crystalline silica	
Year	WAM, ㎎/㎥	N	WAM, ㎎/㎥	N	WAM, ㎎/㎥	N
1994			0.26	10	0.20	26
1996			0.03	42		
1997			0.04	212		
2000			0.06	59	0.30	5
2001			0.10	52		
2002			0.08	381		
2004	0.01	7				
2006	0.01	1				
2008			0.002	2		
2009	0.40	6	0.06	3		
2010	0.06	7	0.03	3		
2011			0.03	10		
2012			0.12	53		
Blank	0.07	3				
Total	0.13	24	0.07	827	0.22	31

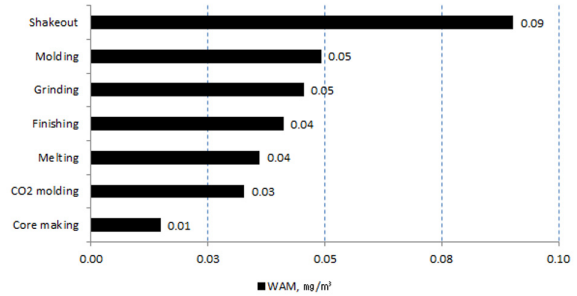


Figure 5. Comparison of respirable crystalline silica concentration in operation by cast of metal industry(KSIC 3-digit)

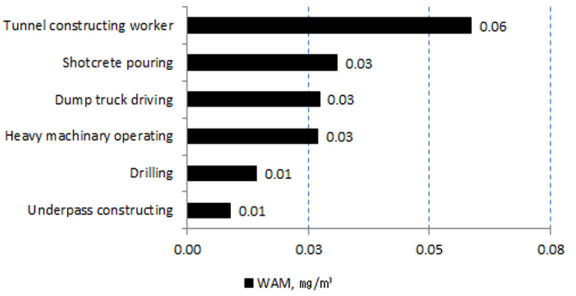


Figure 6. Comparison of respirable crystalline silica concentration in operation by heavy construction industry(KSIC 3-digit)

형 유리규산을 분석하였다. 폐질환연구소의 업무상질병사례집의 사례로 연도 정보가 없는 3개는 Blank로 처리했다. 총 결정형 유리규산은 1994년과 2000년대 초반에 연구가 많이 이루어졌고, 결정형 유리규산만 측정한 연구는 2000년 초반 이후부터 농도 값이 있지만 건수가 많지 않으며 주로 호흡성 결정형 유리규산에 대한 연구가 많은 것을 알 수 있다(Table 4).

4. 금속주조업과 토목건설업의 공정별 농도분포

본 연구대상 문헌들에서는 주물업을 대상으로 결정형 유리규산 농도 연구가 가장 많은 비중을 차지하고 있었다. 그에 비해 상대적으로 건설업에서의 결정형 유리규산의 노출농도 연구는 부족하였다. 그러므로 표준산업분류의 소분류(KSIC 3-digit)에서 금속주조업과 토목건설업을 대상으로 호흡성 결정형 유리규산 농도분포를 분석하여 공정별 노출농도의 차이를 알아보고자 하였다.

1) 금속주조업의 공정별 농도 분포

금속주조업의 전체 시료 수는 570건으로 연구대상 전체의 절반 이상이었다. 호흡성 결정형 유리규산 농도가 가장 높은 공정은 벤토나이트 조형과 형 해체 공정으로 0.09 ㎎/㎥이었고, 연마공정과 조형공정에서 0.05 ㎎/㎥로 고용노동부 노출기준을 초과하였다. 노출기준 미만인 공정은 마무리 및 용해공정이 0.04 ㎎/㎥, 이산화탄소 조형 0.03 ㎎/㎥, 중자 공정이 0.01 ㎎/㎥로 가장 낮았다(Figure 5).

2) 토목건설업의 공정별 농도 분포

토목건설업의 전체 시료 수는 53건 이고 금속주조업에 비해 현저히 낮았다. 호흡성 결정형 유리규산 농도는 버럭처리 공정에서 0.24 ㎎/㎥이였고 터널 건설공정이 0.06 ㎎/㎥이였고 덤프트럭 운전, 중장비 공정 및 숏크리트에서 모두 0.03 ㎎/㎥였다. 드릴공정과 지하도 건설에서 모두 0.01 ㎎/㎥으로 나타났다(Figure 6).

Ⅵ. 고 찰

결정형 유리규산이 노출 될 위험이 높은 직종은 이미 잘 알려져 있다. 웹사이트의 '직업성 폐암 매뉴얼'을 보면 금속광, 탄광, 채석과 석공, 내화벽돌, 주물업, 지하철, 댐, 터널 공사, 규조토 채굴 취급업, 용접, 콘크리트 벽돌 그리고 요업제조 등이다(직업성폐암 감시체계, http://www.isaknox.com). 이 연구의 분석대상이 된 국내 연구보고서 및 학술논문에서도 주로 주물업, 석탄광업, 요업을 대상으로 연구한 문헌들이 많았다. 호흡성 결정형 유리규산의 WAM은 금속 주조업, 석탄 광업, 기타 비금속 광물제품 제조업, 도자기 및 기타 요업 제품 제조업, 토목 건설업에서 0.062 ㎎/㎥ ~ 0.14 ㎎/㎥ 수준으로 확인되었고, 노출기준 0.05 ㎎/㎥을 초과하였다. 대부분 1980년대 후반에서 1990대 초반에 수행한 연구 이므로 산업보건학적 관리에 취약했던 시기였던 만큼 보호구 착용에 미흡할 것으로 예상한다면 근로자는 더욱 높게 노출되었을 것으로 보인다.

작업환경에서 근로자가 취급하는 원료나 채취분진에서의 결정형 유리규산 함량이 높은 업종은 축산업이 80%, 도시 정기 육상 여객 운송업과 도자기 및 기타 요업제품 제조업에서 각각 16.40%, 17.5%이었다. 축산업 자료는 경마장의 모래바닥이며 지하철의 분진에서도 다량 발생하는 것을 알 수 있다. 그러나 이 업종들에서의 연구가 부족하므로 이러한 업종에

서 작업환경측정을 하여 결정형 유리규산의 노출농도를 평가하는 연구가 필요하다고 판단된다.

특히 금속주조업과 토목건설업의 호흡성 결정형 유리규산의 농도 분포를 분석한 결과 각각 0.062 ㎎/㎥, 0.098 ㎎/㎥으로 토목건설업의 WAM 값이 상당히 높은 농도이다. 건설교통부가 발표하는 건설경제 주요통계에 의하면 외형적으로 2001년도 경상가 기준으로 국민총생산(GDP)중 건설투자가 차지하는 비율이 15.9%이고 건설업 생산은 8.2%에 이른다. 건설업 취업자는 2001년도에 약 157만 명이고, 건설업체 수는 '96년도 25,385개소에서 '01년도 47,533개소로 매년 증가하고 있는 추세이다. 이렇듯 건설업이 산업에서 차지하는 비중은 매우 크며 건설공사의 공종 및 공법의 종류 등에 따라 매우 다양한 작업환경을 가지고 있기 때문에 산업안전보건적 측면에서 중요하다고 할 수 있다(KOSHA, 2003). 그러므로 향후 건설업에서의 결정형 유리규산에 대한 노출 관리에 주목해야 한다고 판단된다.

본 연구의 한계점은 각 참고 문헌마다 노출 농도의 기하평균, 기하표준편차, 산술평균, 최소값, 최대값 등 모든 값이 분석된 자료는 거의 없어 완벽한 노출 데이터베이스를 구축하기 어려웠던 점이다. 하지만 WAM 값으로 환산하여 업종별 비교가 가능하도록 하였다. 연구대상 문헌의 대부분이 주물업, 석탄광업, 요업을 대상으로 연구가 주를 이루었기 때문에 건설업, 지하철 등의 연구는 상대적으로 부족하여 전반적인 업종을 분석하기에 한계가 있었다.

본 연구의 대상된 문헌들을 통해 구축한 데이터베이스를 활용하여 향후 위험성 평가와 함께 결합하여 위험성 단계를 분석 할 수 있는 추가 연구가 가능하다고 보며, 업무관련성 조사에도 활용 할 수 있을 것이다. 이후 본 연구 자료를 토대로 추가적인 업종과 공정에 대한 노출자료들이 확대된다면 집중적으로 관리, 개선 되어야할 업종과 공정을 선정하고, 노출관리를 위한 정책 결정, 발암 물질에 노출 된 근로자들의 직업성 암 발생 추이 파악 등 다양한 목적으로 활용 할 수 있을 것으로 기대 된다.

V. 결 론

본 연구에서는 국내 문헌고찰을 통하여 얻은 문헌 18건을 대상으로 결정형 유리규산의 노출 농도 정보를 변수를 정하여 데이터베이스를 구축하였다. 주요 연구결과를 요약하면 다음과 같다.

1. 모든 업종을 대상으로 시료형태 별 농도를 비교해 보았을 때 평균은 총 분진이 19.37 ㎎/㎥, 호흡성 분진 5.61 ㎎/㎥, 총 결정형 유리규산 0.22 ㎎/㎥, 호흡성 결정형 유리규산 0.07 ㎎/㎥, 결정형 유리규산 0.13 ㎎/㎥이였다. 근로자의 호흡기에 직접적으로 영향을 끼치는 호흡성 결정형 유리규산은 고용노동부 노출기준 0.05 ㎎/㎥을 초과하였다.

2. 전체 데이터를 대상으로 호흡성 결정형 유리규산 농도를 표준산업분류 소분류로 분석한 결과 석탄광업에서 0.14 ㎎/㎥, 기타 비금속 광물제품 제조업에서 0.111 ㎎/㎥, 도자기 및 기타 요업 제품 제조업에서 0.108 ㎎/㎥, 토목건설업 0.098 ㎎/㎥ 그리고 금속주조업에서 0.062 ㎎/㎥였다.

3. 호흡성 결정형 유리규산 농도에 대한 표준산업분류 세세분류에 의한 시료 수 가중평균 환산한 결과 가장 높은 업종은 위생용 도자기 제조업이 0.269 ㎎/㎥, 석탄광업 0.14 ㎎/㎥, 기타 일반 도자기 제조업 및 기타 석제품 제조업에서 0.111 ㎎/㎥로 고용노동부 노출기준보다 높게 나타났다.

4. 표준산업분류의 소분류를 기준으로 함량을 비교한 결과 공기 중 분진에서 기타 비금속 광물제품 제조업 7.33%, 도자기 및 기타 요업제품 제조업에서 6.84%이었다. 벌크시료 중 함량이 높은 업종은 축산업이 80%, 도시 정기 육상 여객 운송업과 도자기 및 기타 요업제품 제조업에서 각각 16.40%, 17.5%이었다.

5. 호흡성 결정형 유리규산 농도의 전체 시료 수는 872건이다. 이 중 금속주조업이 570건으로 절반 이상을 차지하고 있으며 공정에서는 벤토나이트 조형과 형해체 공정으로 0.09 ㎎/㎥이었고, 연마공정과 조형공정에서 0.05 ㎎/㎥였다. 노출기준 미만인 공정은 마무리 및 용해공정이 0.04 ㎎/㎥, 이산화탄소 조형 0.03 ㎎/㎥, 중자 공정이 0.01 ㎎/㎥로 가장 낮았다. 토목건설업에서 결정형 유리규산의 농도가 가장 높은 공정은 버럭처리 0.24 ㎎/㎥, 터널 건설공정이 0.06 ㎎/㎥, 덤프트럭 운전, 중장비 공정 및 숏크리트에서 모두 0.03 ㎎/㎥였다.

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Appendix 1. Crystalline silica contents of bulk or airborne dust samples

No	Reference	Year	KSIC-3digit	KSIC-5digit	Operation	Sample type	N	Min (%)	Max (%)	GM (%)	GSD	AM (%)	SD (%)	AMT (%)	Method
1	KWCWS, 2014	2011	Cast of metals	Steel foundries	Grinding	Foundry sand		45	58					51.2	XRD
2	Park et al., 2003	2002	Cast of metals	Gray and malleable iron foundries	Molding	Respirable dust	79	0.05	39.17	1.8	3.44			3.86	FTIR
3	Park et al., 2003	2002	Cast of metals	Gray and malleable iron foundries	Shakeout	Respirable dust	50	0.05	32.79	3.21	3.17			6.25	FTIR
4	Kim et al., 1998	1997	Cast of metals	Gray and malleable iron foundries	Melting	Respirable dust	6					3.53	2.93	3.53	XRD
5	Kim et al., 1998	1997	Cast of metals	Gray and malleable iron foundries	Molding	Respirable dust	13					5.09	3.14	5.09	XRD
6	Kim et al., 1998	1997	Cast of metals	Gray and malleable iron foundries	Core making	Respirable dust	4					4.31	1.85	4.31	XRD
7	Kim et al., 1998	1997	Cast of metals	Gray and malleable iron foundries	Shakeout	Respirable dust	6					5	4.97	5.00	XRD
8	Kim et al., 1998	1997	Cast of metals	Gray and malleable iron foundries	Finishing	Respirable dust	7					3.44	2.18	3.44	XRD
9	Kim et al., 1998	1997	Cast of metals	Gray and malleable iron foundries	Melting	Respirable dust	6					5.94	6.61	5.94	FTIR
10	Kim et al., 1998	1997	Cast of metals	Gray and malleable iron foundries	Molding	Respirable dust	13					4.27	3.81	4.27	FTIR
11	Kim et al., 1998	1997	Cast of metals	Gray and malleable iron foundries	Core making	Respirable dust	4					2.78	1.43	2.78	FTIR
12	Kim et al., 1998	1997	Cast of metals	Gray and malleable iron foundries	Shakeout	Respirable dust	6					4.26	1.74	4.26	FTIR
13	Kim et al., 1998	1997	Cast of metals	Gray and malleable iron foundries	Finishing	Respirable dust	7					4.29	2.49	4.29	FTIR
14	Kim et al., 1998	1997	Cast of metals	Gray and malleable iron foundries	Melting	Respirable dust	3					3.12	1.65	3.12	XRD
15	Kim et al., 1998	1997	Cast of metals	Gray and malleable iron foundries	Molding	Respirable dust	13					4.03	1.96	4.03	XRD
16	Kim et al., 1998	1997	Cast of metals	Gray and malleable iron foundries	Core making	Respirable dust	7					3.75	1.19	3.75	XRD
17	Kim et al., 1998	1997	Cast of metals	Gray and malleable iron foundries	Shakeout	Respirable dust	5					3.89	1.01	3.89	XRD
18	Kim et al., 1998	1997	Cast of metals	Gray and malleable iron foundries	Finishing	Respirable dust	6					3.3	1.22	3.30	XRD
19	Kim et al., 1998	1997	Cast of metals	Gray and malleable iron foundries	Melting	Respirable dust	3					3.54	2.17	3.54	FTIR
20	Kim et al., 1998	1997	Cast of metals	Gray and malleable iron foundries	Molding	Respirable dust	13					5.15	2.46	5.15	FTIR
21	Kim et al., 1998	1997	Cast of metals	Gray and malleable iron foundries	Core making	Respirable dust	7					3.52	2.46	3.52	FTIR
22	Kim et al., 1998	1997	Cast of metals	Gray and malleable iron foundries	Shakeout	Respirable dust	5					6.87	7.19	6.87	FTIR
23	Kim et al., 1998	1997	Cast of metals	Gray and malleable iron foundries	Finishing	Respirable dust	6					5.09	1.67	5.09	FTIR
24	Kim et al., 1998	1997	Cast of metals	Gray and malleable iron foundries	Melting	Bulk	2					8.18	1.39	8.18	XRD
25	Kim et al., 1998	1997	Cast of metals	Gray and malleable iron foundries	Molding	Bulk	15					12.92	15.4	12.92	XRD
26	Kim et al., 1998	1997	Cast of metals	Gray and malleable iron foundries	Core making	Bulk	3					13.19	7.11	13.19	XRD
27	Kim et al., 1998	1997	Cast of metals	Gray and malleable iron foundries	Shakeout	Bulk	5					8.04	3.89	8.04	XRD
28	Kim et al., 1998	1997	Cast of metals	Gray and malleable iron foundries	Finishing	Bulk	4					11.37	7.3	11.37	XRD
29	Kim et al., 1998	1997	Cast of metals	Gray and malleable iron foundries	Melting	Bulk	2					6.23	6.23	6.23	FTIR
30	Kim et al., 1998	1997	Cast of metals	Gray and malleable iron foundries	Molding	Bulk	16					6.99	6.99	6.99	FTIR
31	Kim et al., 1998	1997	Cast of metals	Gray and malleable iron foundries	Core making	Bulk	3					11.01	11.01	11.01	FTIR
32	Kim et al., 1998	1997	Cast of metals	Gray and malleable iron foundries	Shakeout	Bulk	4					5.68	5.68	5.68	FTIR
33	Kim et al., 1998	1997	Cast of metals	Gray and malleable iron foundries	Finishing	Bulk	5					5.15	5.15	5.15	FTIR
34	Phee et al., 1997	1996	Cast of metals	Gray and malleable iron foundries	Molding	Respirable dust	11	1.23	15.87	4.32	1.96			5.42	FTIR
35	Phee et al., 1997	1996	Cast of metals	Gray and malleable iron foundries	Shakeout	Respirable dust	7	2.64	7.53	4.84	1.41			5.13	FTIR

No	Reference	Year	KSIC-3digit	KSIC-5digit	Operation	Sample type	N	Min (%)	Max (%)	GM (%)	GSD	AM (%)	SD (%)	AMT (%)	Method
36	Phee et al., 1997	1996	Cast of metals	Gray and malleable iron foundries	Finishing	Respirable dust	2	4.41	6.51	5.36	1.32			5.57	FTIR
37	Phee et al., 1997	1996	Cast of metals	Gray and malleable iron foundries	Melting	Respirable dust	2	1.88	6	3.36	2.27			4.70	FTIR
38	Phee et al., 1997	1996	Cast of metals	Gray and malleable iron foundries	Molding	Respirable dust	10	2.51	13.99	6.35	1.74			7.40	FTIR
39	Phee et al., 1997	1996	Cast of metals	Gray and malleable iron foundries	Shakeout	Respirable dust	6	3.5	7.53	4.59	1.35			4.80	FTIR
40	Phee et al., 1997	1996	Cast of metals	Gray and malleable iron foundries	Finishing	Respirable dust	4	9.3	22.67	14.69	1.5			15.95	FTIR
41	Phee et al., 1997	1996	Cast of metals	Gray and malleable iron foundries	Molding	Bulk	13	0.15	18.1			4.54	4.45	4.54	FTIR
42	Phee et al., 1997	1996	Cast of metals	Gray and malleable iron foundries	Shakeout, finishing	Bulk	7	0.33	8.83			4.7	4.69	4.70	FTIR
43	KWCWS, 2014	2011	Farming of animals	Farming of horses,sheep and goats	Lungeing	Total dust						1.7		1.7	XRD
44	KWCWS, 2014	2011	Farming of animals	Farming of horses,sheep and goats	Lungeing	Total dust						1.6		1.6	XRD
45	KWCWS, 2014	2011	Farming of animals	Farming of horses,sheep and goats	Lungeing	Ground sand						80		80	XRD
46	Yoo et al.,2003	2001	Heavy construction	Construction of bridges, tunnels and railways	Tunnel constructing	Respirable dust	15					4.8		4.8	FTIR
47	Yoo et al.,2003	2001	Heavy construction	Construction of bridges, tunnels and railways	Drilling	Respirable dust	6					2.1		2.1	FTIR
48	Yoo et al.,2003	2001	Heavy construction	Construction of bridges, tunnels and railways	Pay Loader operating	Respirable dust	8					6.9		6.9	FTIR
49	Yoo et al.,2003	2001	Heavy construction	Construction of bridges, tunnels and railways	Pay Loader operating	Respirable dust	8					5.3		5.3	FTIR
50	Yoo et al.,2003	2001	Heavy construction	Construction of bridges, tunnels and railways	Shotcrete pouring	Respirable dust	2					1.6		1.6	FTIR
51	Yoo et al.,2003	2001	Heavy construction	Construction of bridges, tunnels and railways	Dump truck driving	Respirable dust	10					4.1		4.1	FTIR
52	Yoo et al.,2003	2001	Heavy construction	Construction of bridges, tunnels and railways	Heavy machine operating	Respirable dust	3					3.2		3.2	FTIR
53	Kim et al., 2009	2009	Manufacture of cement, lime and plaster and its products	Manufacture of cement		Portland cement	8					0.32		0.32	XRD
54	Kim et al., 2009	2009	Manufacture of cement, lime and plaster and its products	Manufacture of cement		White cement	2	0	0.67					0.34	XRD
55	Kim et al., 2008	2008	Manufacture of cement, lime and plaster and its products	Manufacture of cement		Cement	1					0.2		0.20	XRD
56	Kim et al., 1999	1997	Manufacture of cement, lime and plaster and its products	Manufacture of other refractory ceramic products		Respirable dust	3					4.75	1.89	4.75	XRD
57	Kim et al., 1999	1997	Manufacture of cement, lime and plaster and its products	Manufacture of other refractory ceramic products		Respirable dust	3					2.58	1.29	2.58	FTIR
58	Kim et al., 1999	1997	Manufacture of ceramic ware	Manufacture of other non-structural, non-refractory ceramic ware		Respirable dust	16					7.18	6.51	7.18	XRD
59	Kim et al., 1999	1997	Manufacture of ceramic ware	Manufacture of other non-structural, non-refractory ceramic ware		Respirable dust	14					10.33	9.7	10.33	FTIR
60	KWCWS, 2014	2010	Manufacture of ceramic ware	Manufacture of sanitary ceramic ware	Developing, shapinge, forming	Gypsum powder						0.5		0.5	XRD
61	KWCWS, 2014	2009	Manufacture of ceramic ware	Manufacture of sanitary ceramic ware	Mixing	Total dust	2	4.872	6.913					5.89	FTIR
62	KWCWS, 2014	2009	Manufacture of ceramic ware	Manufacture of sanitary ceramic ware	Mixing	Total dust	2	2.168	2.868					2.52	FTIR
63	Kim et al., 2010	2010	Manufacture of ceramic ware	Manufacture of sanitary ceramic ware		Gypsum powder	1					0.5		0.50	XRD
64	Kim et al., 2010	2010	Manufacture of ceramic ware	Manufacture of sanitary ceramic ware		Forming products	1					35.9		35.90	XRD
65	Kim et al., 2010	2010	Manufacture of ceramic ware	Manufacture of sanitary ceramic ware		Raw metaerial	7	ND	56.6			26.7		26.70	XRD
66	Kim et al., 2010	2010	Manufacture of ceramic ware	Manufacture of sanitary ceramic ware	Forming	Respirable dust	NA					46		46.00	XRD
67	Kim et al., 1999	1997	Manufacture of ceramic ware	Manufacture of structural refractory ceramic products	Others(building exterior insulation, polishing and casting subsidiary)	Respirable dust	8					7.54	7.95	7.54	XRD

No	Reference	Year	KSIC-3digit	KSIC-5digit	Operation	Sample type	N	Min (%)	Max (%)	GM (%)	GSD	AM (%)	SD (%)	AMT (%)	Method
68	Kim et al., 1999	1997	Manufacture of ceramic ware	Manufacture of structural refractory ceramic products	Others(building exterior insulation, polishing and casting subsidiary)	Respirable dust	8					7.97	6.57	7.97	FTIR
69	Oh et al., 1994	1994	Manufacture of ceramic ware	Manufacture of structural refractory ceramic products		Total dust	11					8.03	4.8	8.03	FTIR
70	Oh et al., 1994	1994	Manufacture of ceramic ware	Manufacture of structural refractory ceramic products		Total, respirable dust	10					1.32	0.69	1.32	FTIR
71	Oh et al., 1994	1994	Manufacture of ceramic ware	Manufacture of structural refractory ceramic products		Total, respirable dust	13					5.59	3.6	5.59	FTIR
72	Oh et al., 1994	1994	Manufacture of ceramic ware	Manufacture of structural refractory ceramic products		Glaze	1					9.09		9.09	FTIR
73	Oh et al., 1994	1994	Manufacture of ceramic ware	Manufacture of structural refractory ceramic products		Precipitated dust	1					7.32		7.32	FTIR
74	Oh et al., 1994	1994	Manufacture of ceramic ware	Manufacture of structural refractory ceramic products		Raw metaerial	1					11.75		11.75	FTIR
75	Oh et al., 1994	1994	Manufacture of ceramic ware	Manufacture of structural refractory ceramic products		Glaze	1					10.94		10.94	FTIR
76	Oh et al., 1994	1994	Manufacture of ceramic ware	Manufacture of structural refractory ceramic products		Raw metaerial	1					10.11		10.11	FTIR
77	Oh et al., 1994	1994	Manufacture of ceramic ware	Manufacture of structural refractory ceramic products		Raw metaerial	1					0.5		0.50	FTIR
78	Oh et al., 1994	1994	Manufacture of ceramic ware	Manufacture of structural refractory ceramic products		Bulk	1					5.03		5.03	FTIR
79	Oh et al., 1994	1994	Manufacture of ceramic ware	Manufacture of structural refractory ceramic products		Precipitated dust	1					0.72		0.72	FTIR
80	Kim et al., 1999	1997	Manufacture of coke and briquettes	Manufacture of briquettes and other coal products	Briquets	Respirable dust	3					3.41	1.3	3.41	XRD
81	Kim et al., 1999	1997	Manufacture of coke and briquettes	Manufacture of briquettes and other coal products	Briquets	Respirable dust	3					3.01	1.35	3.01	FTIR
82	Kim et al., 1999	1997	Manufacture of glass and glass products	Manufacture of all other glass and its products n.e.c.		Respirable dust	3					4.52	5.63	4.52	XRD
83	Kim et al., 1999	1997	Manufacture of glass and glass products	Manufacture of all other glass and its products n.e.c.		Respirable dust	1					2.53		2.53	FTIR
84	KWCWS, 2014		Manufacture of other chemical products	Manufacture of general paints and similar products	Paints mixing	Paint	2					10.53		10.53	XRD
85	KWCWS, 2014		Manufacture of other chemical products	Manufacture of general paints and similar products	Paints mixing	Calsite, clay	2					0.95		0.95	
86	KWCWS, 2014	2010	Manufacture of other non-metallic mineral products	Manufacture of non-metallic crushed mineral products	Crushing, cleaning	Tuff	1					6		6	
87	Kim et al., 1999	1997	Manufacture of other non-metallic mineral products	Manufacture of other stone products		Respirable dust	6					5.47	1.86	5.47	XRD
88	Kim et al., 1999	1997	Manufacture of other non-metallic mineral products	Manufacture of other stone products		Respirable dust	4					10.12	4.96	10.12	FTIR
89	Shin et al., 2002	2000	Mining of coal and lignite	Mining of coal and lignite	Rock drilling	Total dust	2	0.42	9.76					5.09	FTIR
90	Shin et al., 2002	2000	Mining of coal and lignite	Mining of coal and lignite	Beam construction	Respirable dust	3					2.6	4.2	2.60	FTIR
91	Shin et al., 2002	2000	Mining of coal and lignite	Mining of coal and lignite	Rock drilling	Respirable dust	8					6.3	6.7	6.30	FTIR
92	Shin et al., 2002	2000	Mining of coal and lignite	Mining of coal and lignite	Coal face	Total dust	1					2.36		2.36	FTIR
93	Shin et al., 2002	2000	Mining of coal and lignite	Mining of coal and lignite	Coal face	Respirable dust	6					0.39	0.3	0.39	FTIR
94	Shin et al., 2002	2000	Mining of coal and lignite	Mining of coal and lignite	Loading, transportation	Total dust	1					0.61		0.61	FTIR
95	Shin et al., 2002	2000	Mining of coal and lignite	Mining of coal and lignite	Loading, transportation	Respirable dust	6					4.7	1.4	4.70	FTIR
96	Lee & Lee, 1989	1989	Mining of coal and lignite	Mining of coal and lignite	Coal face	Respirable dust	3			1.52	2.34	2.1	1.71	2.1	FTIR
97	Yoon & Lee, 1988	1987	Mining of coal and lignite	Mining of coal and lignite	Drilling	Respirable dust	41	0	18.9	2.9	4.3	5.5	5.3	5.5	FTIR
98	Yoon & Lee, 1988	1987	Mining of coal and lignite	Mining of coal and lignite	Coal cutting	Respirable dust	48	0	13.5	0.6	4.4	1.8	3.1	1.8	FTIR
99	Yoon & Lee, 1988	1987	Mining of coal and lignite	Mining of coal and lignite	Hauling	Respirable dust	13	0	8.9	1.2	2.3	2.4	2.6	2.4	FTIR
100	Yoon & Lee, 1988	1987	Mining of coal and lignite	Mining of coal and lignite	Separating	Respirable dust	15	0	5.8	1.2	3.1	1.7	1.4	1.7	FTIR

No	Reference	Year	KSIC-3digit	KSIC-5digit	Operation	Sample type	N	Min (%)	Max (%)	GM (%)	GSD	AM (%)	SD (%)	AMT (%)	Method
101	Yoon & Lee, 1988	1987	Mining of coal and lignite	Mining of coal and lignite	Drilling	Respirable dust	12	0	14.8	2.5	4.9	5.2	5	5.2	
102	Yoon & Lee, 1988	1987	Mining of coal and lignite	Mining of coal and lignite	Drilling helper	Respirable dust	13	0	16.6	2.9	3.7	4.8	4.3	4.8	
103	Yoon & Lee, 1988	1987	Mining of coal and lignite	Mining of coal and lignite	Coal cutting	Respirable dust	9	0	11.6	1.6	4.5	3.1	3.5	3.1	
104	Yoon & Lee, 1988	1987	Mining of coal and lignite	Mining of coal and lignite	Coal cutting helper	Respirable dust	10	0	2.2	0.3	3.3	0.6	0.7	0.6	
105	Choi et al., 2000	2000	Mining of iron ores	Mining of iron ores		Total dust	2					1	0.65	1	FTIR
106	Choi et al., 2000	2000	Mining of iron ores	Mining of iron ores		Total dust	1					2.9		2.9	FTIR
107	Choi et al., 2000	2000	Mining of iron ores	Mining of iron ores		Total dust	1					0.6		0.6	FTIR
108	Choi et al., 2000	2000	Mining of iron ores	Mining of iron ores		Respirable dust	1					0.9		0.9	FTIR
109	Choi et al., 2000	2000	Mining of iron ores	Mining of iron ores		Respirable dust	2					5.7	7.1	5.7	FTIR
110	Choi et al., 2000	2000	Mining of iron ores	Mining of iron ores		Respirable dust	3					0.65	0.52	0.65	FTIR
111	Choi et al., 2000	2000	Mining of iron ores	Mining of iron ores		Respirable dust	7					11.2	16.6	11.2	FTIR
112	KWCWS, 2014	2010	Transit and ground passenger transportation	Commuter rail systems	Frequency dividing	Sedimentation dust	1					12		12	XRD
113	KWCWS, 2014	2010	Transit and ground passenger transportation	Commuter rail systems	Track device installation	Sedimentation dust	1					23		23	XRD

Appendix 2. Crystalline silica concentration of airborne dust samples

No	Reference	Year	KSIC-3digit	KSIC-5digit	Operation	Sample type	Min (mg/m^3)	Max (mg/m^3)	GM (mg/m^3)	GSD	AM (mg/m^3)	SD (mg/m^3)	AMT (%)	Method
1	KWCWS, 2014	NA	Cast of Metals	Steel foundries	Grinding	Personal					0.04		0.04	XRD
2	KWCWS, 2014	NA	Cast of Metals	Steel foundries	Grinding	Personal					0.034		0.03	XRD
3	KWCWS, 2014	NA	Cast of Metals	Steel foundries	Heating	Area					0.136		0.14	
4	KOSHA, 2007	2004	Manufacture of ceramic ware	Manufacture of structural refractory ceramic products	Crushing	Personal	0.00721	0.02426			0.016		0.016	
5	KOSHA, 2007	2004	Manufacture of ceramic ware	Manufacture of structural refractory ceramic products	Drying	Personal	0.00446	0.05243			0.028		0.028	
6	KWCWS, 2014	2010	Manufacture of ceramic ware	Manufacture of sanitary ceramic ware	Forming						0.08		0.08	
7	KOSHA, 2007	2004	Manufacture of other chemical products	Manufacture of Ceramic Enamels and Related Products	Mixing	Personal	0.00036	0.00384			0.0024		0.0024	
8	KWCWS, 2014	2006	Manufacture of other chemical products	Manufacture of general paints and similar products	Painting	Personal	0.006	0.013					0.009	XRD
9	KWCWS, 2014	2010	Manufacture of other non-metallic mineral products	Manufacture of non-metallic crushed mineral products	Crushing	Personal					0.028		0.03	XRD
10	KWCWS, 2014	2010	Manufacture of other non-metallic mineral products	Manufacture of non-metallic crushed mineral products	Heavy machinary operating	Area					0.031		0.03	XRD
11	KWCWS, 2014	2010	Manufacture of other non-metallic mineral products	Manufacture of non-metallic crushed mineral products	Conveyor belt	Area					0.173		0.17	XRD
12	KWCWS, 2014	2010	Manufacture of other non-metallic mineral products	Manufacture of non-metallic crushed mineral products	Stone dust compression	Personal					0.017		0.02	
13	KWCWS, 2014	2010	Manufacture of other non-metallic mineral products	Manufacture of non-metallic crushed mineral products	Stone dust compression	Personal					0.082		0.08	
14	KWCWS, 2014	2010	Manufacture of other non-metallic mineral products	Manufacture of non-metallic crushed mineral products	Heavy machinary operating	Area	0.031	0.04					0.04	
15	KWCWS, 2014	2009	Manufacture of other non-metallic mineral products	Manufacture of other stone products	Cutting	Area					0.585		0.59	XRD
16	KWCWS, 2014	2009	Manufacture of other non-metallic mineral products	Manufacture of other stone products	Cutting, grinding	Area					0.769		0.77	XRD
17	KWCWS, 2014	2009	Manufacture of other non-metallic mineral products	Manufacture of other stone products	Carving	Area					0.05		0.05	XRD
18	KWCWS, 2014	2009	Manufacture of other non-metallic mineral products	Manufacture of other stone products	Surface treatment	Area					0.128		0.13	XRD
19	KWCWS, 2014	2009	Quarrying of stone,sand and gravel	Quarrying of crushed and broken building stone	Grinding	Area					0.796		0.80	XRD
20	KWCWS, 2014	2009	Quarrying of stone,sand and gravel	Quarrying of crushed and broken building stone	Carving	Area					0.05		0.05	XRD

Appendix 3. Respirable crystalline silica concentration of airborne dust samples

No	Reference	Year	KSIC-3digit	KSIC-5digit	Operation	Sample type	Min (mg/m^3)	Max (mg/m^3)	GM (mg/m^3)	GSD	AM (mg/m^3)	SD (mg/m^3)	AMT (%)	Method
21	KWCWS, 2014	2011	Cast of Metals	Steel foundries	Molding	Personal					0.11		0.11	
22	KWCWS, 2014	2011	Cast of Metals	Steel foundries	Melting	Personal					0.019		0.02	
23	KWCWS, 2014	2011	Cast of Metals	Steel foundries	Molding	Personal					0.036		0.04	
24	KWCWS, 2014	2011	Cast of Metals	Steel foundries	Melting	Personal					0.025		0.03	
25	KWCWS, 2014	2011	Cast of Metals	Steel foundries	Molding	Area					0.015		0.02	
26	KWCWS, 2014	2011	Cast of Metals	Steel foundries	Grinding	Area					0.056		0.06	
27	KWCWS, 2014	2011	Cast of Metals	Steel foundries	Grinding	Area					0.035		0.04	
28	Park et al., 2003	2002	Cast of metals	Gray and malleable iron foundries	Molding	Personal	0.0007	0.3045	0.0206	3.8962			0.052	FTIR
29	Park et al., 2003	2002	Cast of metals	Gray and malleable iron foundries	Shakeout	Personal	0.0014	0.3757	0.0426	3.7547			0.102	FTIR
30	Park et al., 2003	2002	Cast of metals	Gray and malleable iron foundries	Molding	Personal	0.0295	0.3045	0.0859	1.8908			0.11	FTIR
31	Park et al., 2003	2002	Cast of metals	Gray and malleable iron foundries	Shakeout	Personal	0.014	0.3757	0.1006	2.4303			0.15	FTIR
32	Park et al., 2003	2002	Cast of metals	Gray and malleable iron foundries	Molding	Personal	0.0007	0.0419	0.0139	2.7047			0.02	FTIR
33	Park et al., 2003	2002	Cast of metals	Gray and malleable iron foundries	Shakeout	Personal	0.0014	0.0757	0.0186	3.1963			0.04	FTIR
34	Park et al., 2003	2002	Cast of metals	Gray and malleable iron foundries	Molding	Personal	0.0007	0.1047	0.0161	2.8377			0.03	FTIR
35	Park et al., 2003	2002	Cast of metals	Gray and malleable iron foundries	Shakeout	Personal	0.0014	0.0678	0.016	3.222			0.03	FTIR
36	Park et al., 2003	2002	Cast of metals	Gray and malleable iron foundries	Molding	Personal	0.0347	0.3045	0.0926	1.8589			0.11	FTIR
37	Park et al., 2003	2002	Cast of metals	Gray and malleable iron foundries	Shakeout	Personal	0.0111	0.3757	0.0941	2.4645			0.14	FTIR
38	Park et al., 2003	2002	Cast of metals	Gray and malleable iron foundries	CO2molding	Personal	0.0014	0.3757	0.0316	1.306			0.03	FTIR
39	Park et al., 2003	2002	Cast of metals	Gray and malleable iron foundries	Bentonite molding	Personal	0.0007	0.3154	0.0498	3.0926			0.09	FTIR
40	Kim et al., 1998	1997	Cast of metals	Gray and malleable iron foundries	Melting	Personal	0.00823	0.06971	0.01769	2.48			0.027	XRD
41	Kim et al., 1998	1997	Cast of metals	Gray and malleable iron foundries	Molding	Personal	0.01108	0.03313	0.02139	1.34			0.022	XRD
42	Kim et al., 1998	1997	Cast of metals	Gray and malleable iron foundries	Core making	Personal	0.01271	0.02227	0.01538	1.29			0.016	XRD
43	Kim et al., 1998	1997	Cast of metals	Gray and malleable iron foundries	Shakeout	Personal	0.00577	0.03929	0.01898	2.03			0.024	XRD
44	Kim et al., 1998	1997	Cast of metals	Gray and malleable iron foundries	Finishing	Personal	0.01354	0.05683	0.02314	1.67			0.026	XRD
45	Kim et al., 1998	1997	Cast of metals	Gray and malleable iron foundries	Melting	Personal	0.00246	0.14009	0.023	4.71			0.076	FTIR
46	Kim et al., 1998	1997	Cast of metals	Gray and malleable iron foundries	Molding	Personal	0.00206	0.06072	0.01585	3.2			0.031	FTIR
47	Kim et al., 1998	1997	Cast of metals	Gray and malleable iron foundries	Core making	Personal	0.00766	0.02534	0.01084	1.77			0.013	FTIR
48	Kim et al., 1998	1997	Cast of metals	Gray and malleable iron foundries	Shakeout	Personal	0.00599	0.07543	0.02385	2.45			0.036	FTIR
49	Kim et al., 1998	1997	Cast of metals	Gray and malleable iron foundries	Finishing	Personal	0.00195	0.13267	0.03175	3.83			0.078	FTIR
50	Kim et al., 1998	1997	Cast of metals	Gray and malleable iron foundries	Melting	Area	0.01181	0.01576	0.01387	1.16			0.014	XRD
51	Kim et al., 1998	1997	Cast of metals	Gray and malleable iron foundries	Molding	Area	0.00882	0.04227	0.01709	1.58			0.019	XRD
52	Kim et al., 1998	1997	Cast of metals	Gray and malleable iron foundries	Core making	Area	0.00725	0.02725	0.01319	1.56			0.015	XRD
53	Kim et al., 1998	1997	Cast of metals	Gray and malleable iron foundries	Shakeout	Area	0.00822	0.01829	0.01267	1.39			0.013	XRD
54	Kim et al., 1998	1997	Cast of metals	Gray and malleable iron foundries	Finishing	Area	0.00807	0.03795	0.02084	1.78			0.025	XRD

No	Reference	Year	KSIC-3digit	KSIC-5digit	Operation	Sample type	Min (mg/m^3)	Max (mg/m^3)	GM (mg/m^3)	GSD	AM (mg/m^3)	SD (mg/m^3)	AMT (%)	Method
55	Kim et al., 1998	1997	Cast of metals	Gray and malleable iron foundries	Melting	Area	0.01016	0.03183	0.01611	1.83			0.019	FTIR
56	Kim et al., 1998	1997	Cast of metals	Gray and malleable iron foundries	Molding	Area	0.00296	0.09492	0.02263	2.62			0.036	FTIR
57	Kim et al., 1998	1997	Cast of metals	Gray and malleable iron foundries	Core making	Area	0.00402	0.0392	0.0114	2.22			0.016	FTIR
58	Kim et al., 1998	1997	Cast of metals	Gray and malleable iron foundries	Shakeout	Area	0.00317	0.05627	0.0171	2.72			0.028	FTIR
59	Kim et al., 1998	1997	Cast of metals	Gray and malleable iron foundries	Finishing	Area	0.01566	0.10354	0.03085	1.95			0.039	FTIR
60	Phee et al., 1997	1996	Cast of metals	Gray and malleable iron foundries	Molding	Personal	0.011	0.0958	0.02775				0.0376	FTIR
61	Phee et al., 1997	1996	Cast of metals	Gray and malleable iron foundries	Shakeout	Personal	0.01969	0.13926	0.04563				0.0590	FTIR
62	Phee et al., 1997	1996	Cast of metals	Gray and malleable iron foundries	Finishing	Personal	0.02017	0.02241	0.02126				0.0213	FTIR
63	Phee et al., 1997	1996	Cast of metals	Gray and malleable iron foundries	Melting	Area	0.01372	0.01684	0.01519				0.0152	FTIR
64	Phee et al., 1997	1996	Cast of metals	Gray and malleable iron foundries	Molding	Area	0.00996	0.03632	0.02032				0.0200	FTIR
65	Phee et al., 1997	1996	Cast of metals	Gray and malleable iron foundries	Shakeout	Area	0.01475	0.05041	0.03091				0.0286	FTIR
66	Phee et al., 1997	1996	Cast of metals	Gray and malleable iron foundries	Finishing	Area	0.01028	0.11333	0.03457				0.0409	FTIR
67	KWCWS, 2014	2012	Farming of animals	Farming of horses,sheep and goats	Race ground	Personal					0.02		0.02	XRD
68	KWCWS, 2014	2011	Farming of animals	Farming of horses,sheep and goats	Race ground	Area					0.018		0.02	XRD
69	KWCWS, 2014	2011	Farming of animals	Farming of horses,sheep and goats	Race ground	Area					0.026		0.03	XRD
70	KWCWS, 2014	2011	Heavy construction	Construction of bridges, tunnels and railways	Under pass constructing	Area	0.004	0.014			0.009		0.01	XRD
71	Yoo et al.,2003	2001	Heavy construction	Construction of bridges, tunnels and railways	Tunnel constructing worker	Personal		0.48	0.021	4.19			0.06	FTIR
72	Yoo et al.,2003	2001	Heavy construction	Construction of bridges, tunnels and railways	Drilling	Personal		0.0265	0.01	2.34			0.01	FTIR
73	Yoo et al.,2003	2001	Heavy construction	Construction of bridges, tunnels and railways	Pay loader operating	Personal		0.474	0.0638	5.46			0.27	FTIR
74	Yoo et al.,2003	2001	Heavy construction	Construction of bridges, tunnels and railways	Pay loader operating	Personal		0.333	0.116	2.92			0.21	FTIR
75	Yoo et al.,2003	2001	Heavy construction	Construction of bridges, tunnels and railways	Shotcrete pouring	Personal		0.0387	0.027	1.7			0.03	FTIR
76	Yoo et al.,2003	2001	Heavy construction	Construction of bridges, tunnels and railways	Dump truck driving	Personal		0.0436	0.023	1.8			0.03	FTIR
77	Yoo et al.,2003	2001	Heavy construction	Construction of bridges, tunnels and railways	Heavy machinary operating	Personal		0.0438	0.023	1.76			0.03	FTIR
78	Kim et al., 2008	2008	Manufacture of basic iron and steel	Manufacture of basic iron	Heating	Area	ND	0.0034			0.0017		0.0017	FTIR
79	Kim et al., 1999	1997	Manufacture of cement,lime and plaster and its products	Manufacture of other refractory ceramic products	Concrete manufacturing	Personal	0.01139	0.01529	0.01336	1.16			0.014	XRD
80	Kim et al., 1999	1997	Manufacture of cement,lime and plaster and its products	Manufacture of other refractory ceramic products	Concrete manufacturing	Personal	0	0.01574	0.00764	2.78			0.013	FTIR
81	KWCWS, 2014	2009	Manufacture of cement,lime and plaster and its products	Manufacture of ready-mixconcrete facilities and industrial supplies	Mixer,hopper,conveyer belt clean	Area	0.041	0.084					0.06	XRD
82	Kim et al., 1999	1997	Manufacture of ceramic ware	Manufacture of other non-structural, non-refractory ceramic ware		Personal	0.00697	0.1352	0.02227	2.27			0.031	XRD

No	Reference	Year	KSIC-3digit	KSIC-5digit	Operation	Sample type	Min (mg/m^3)	Max (mg/m^3)	GM (mg/m^3)	GSD	AM (mg/m^3)	SD (mg/m^3)	AMT (%)	Method
83	Kim et al., 1999	1997	Manufacture of ceramic ware	Manufacture of other non-structural, non-refractory ceramic ware		Personal	0	0.55399	0.02597	7.59			0.203	FTIR
84	Oh et al., 1994	1994	Manufacture of ceramic ware	Manufacture of sanitary ceramic ware	Sanitary ware	Personal			0.0279	10.2			0.414	FTIR
85	Kim et al., 2010	2010	Manufacture of ceramic ware	Manufacture of sanitary ceramic ware	Forming	Personal					0.08		0.08	XRD
86	Kim et al., 2010	2010	Manufacture of ceramic ware	Manufacture of sanitary ceramic ware	Developing	Personal					ND		0	XRD
87	Kim et al., 2010	2010	Manufacture of ceramic ware	Manufacture of sanitary ceramic ware	Shaping	Personal					ND		0	XRD
88	Kim et al., 1999	1997	Manufacture of ceramic ware	Manufacture of structural refractory ceramic products	Others(building exterior insulation, polishing and casting subsidiary)	Personal	0.00663	0.03071	0.01033	1.56			0.011	XRD
89	Kim et al., 1999	1997	Manufacture of ceramic ware	Manufacture of structural refractory ceramic products	Others(building exterior insulation, polishing and casting subsidiary)	Personal	0	0.06514	0.0149	3.63			0.034	FTIR
90	Oh et al., 1994	1994	Manufacture of ceramic ware	Manufacture of structural refractory ceramic products		Personal			0.0058	11.2			0.107	FTIR
91	Kim et al., 1999	1997	Manufacture of coke and briquettes	Manufacture of briquettes and other coal products	Briquets	Personal	0.01161	0.01554	0.01317	1.16			0.013	XRD
92	Kim et al., 1999	1997	Manufacture of coke and briquettes	Manufacture of briquettes and other coal products	Briquets	Personal	0	0.03526	0.01267	2.52			0.019	FTIR
93	Kim et al., 1999	1997	Manufacture of glass and glass products	Manufacture of all other glass and its products n.e.c.		Personal	0.00685	0.08613	0.01656	4.18			0.046	XRD
94	Kim et al., 1999	1997	Manufacture of glass and glass products	Manufacture of all other glass and its products n.e.c.		Personal	0	0.01183	0.01183				0.012	FTIR
95	Kim et al., 2012	2008-2012	Manufacture of other non-metallic mineral products	Manufacture of other stone products	Stone processing	Personal	NA	0.796			0.149		0.15	XRD
96	Kim et al., 2012	2008-2012	Manufacture of other non-metallic mineral products	Manufacture of other stone products	Stone installation	Personal	NA	0.133			0.038		0.04	XRD
97	Kim et al., 2014	2012	Manufacture of other non-metallic mineral products	Manufacture of other stone products	Stone grinding	Personal	0.049	0.554	0.17	2.181	0.225	0.175	0.23	FTIR
98	Kim et al., 1999	1997	Manufacture of other non-metallic mineral products	Manufacture of other stone products	Stone	Personal	0.00628	0.32708	0.02408	4.39			0.072	XRD
99	Kim et al., 1999	1997	Manufacture of other non-metallic mineral products	Manufacture of other stone products	Stone	Personal	0	0.03807	0.01716	2.25			0.024	FTIR
100	Shin, et al., 2002	2000	Mining of coal and lignite	Mining of coal and lignite	Coal mine	Personal	0.001	0.45	0.05	4.2			0.1	FTIR
101	Choi et al., 2000	2000	Mining of iron ores	Mining of iron ores	Rock drilling	Personal	0.0001	0.005					0.0011	FTIR
102	Choi et al., 2000	2000	Mining of iron ores	Mining of iron ores	Hauling	Personal	0.0001	0.004					0.0010	FTIR
103	Choi et al., 2000	2000	Quarrying of stone,sand and gravel	Quarrying of limestone and gypsum	Hauling	Personal	0.002	0.041	0.004	2.9			0.007	FTIR
104	Choi et al., 2000	2000	Quarrying of stone,sand and gravel	Quarrying of limestone and gypsum	Loading	Personal	0.002	0.007					0.0039	FTIR
105	Choi et al., 2000	2000	Quarrying of stone,sand and gravel	Quarrying of limestone and gypsum	Drilling, blasting	Personal	0.002	0.004	0.003	1.4			0.0032	FTIR
106	Choi et al., 2000	2000	Quarrying of stone,sand and gravel	Quarrying of limestone and gypsum	Milling	Personal	0.0001	0.002					0.0006	FTIR
107	Choi et al., 2000	2000	Quarrying of stone,sand and gravel	Quarrying of limestone and gypsum		Personal	0.0001	0.002					0.0006	FTIR
108	Choi et al., 2000	2000	Quarrying of stone,sand and gravel	Quarrying of limestone and gypsum		Personal	0.0001	0.009					0.0018	FTIR
109	Choi et al., 2000	2000	Quarrying of stone,sand and gravel	Quarrying of limestone and gypsum		Personal	0.0001	0.003					0.0008	pFTIR

Appendix 4. Respirable dust concentration of airborne dust samples

No	Reference	Year	KSIC-3digit	KSIC-5digit	Operation	Sample type	Min (mg/m^3)	Max (mg/m^3)	GM (mg/m^3)	GSD	AM (mg/m^3)	SD (mg/m^3)	AMT (%)	Method
110	Park et al., 2003	2002	Cast of Metals	Gray and malleable iron foundries	Molding	Personal	0.3024	7.0428	1.1457	1.9271			1.42	Weighing
111	Park et al., 2003	2002	Cast of Metals	Gray and malleable iron foundries	Shakeout	Personal	0.1524	5.0683	1.3258	2.3071			1.88	Weighing
112	Kim et al., 1998	1997	Cast of Metals	Gray and malleable iron foundries	Melting	Personal	0.4	1.03	0.69	1.44			0.74	Weighing
113	Kim et al., 1998	1997	Cast of Metals	Gray and malleable iron foundries	Molding	Personal	0.16	1.18	0.46	1.66			0.52	Weighing
114	Kim et al., 1998	1997	Cast of Metals	Gray and malleable iron foundries	Core making	Personal	0.25	0.66	0.46	1.4			0.49	Weighing
115	Kim et al., 1998	1997	Cast of Metals	Gray and malleable iron foundries	Shakeout	Personal	0.18	1.22	0.53	2.03			0.68	Weighing
116	Kim et al., 1998	1997	Cast of Metals	Gray and malleable iron foundries	Finishing	Personal	0.3	3.1	1.06	2.19			1.44	Weighing
117	Kim et al., 1998	1997	Cast of Metals	Gray and malleable iron foundries	Melting	Area	0.13	1	0.38	2.03			0.49	Weighing
118	Kim et al., 1998	1997	Cast of Metals	Gray and malleable iron foundries	Molding	Area	0.05	2.32	0.34	2.55			0.53	Weighing
119	Kim et al., 1998	1997	Cast of Metals	Gray and malleable iron foundries	Core making	Area	0.26	0.74	0.43	1.49			0.47	Weighing
120	Kim et al., 1998	1997	Cast of Metals	Gray and malleable iron foundries	Shakeout	Area	0.22	0.55	0.36	1.43			0.38	Weighing
121	Kim et al., 1998	1997	Cast of Metals	Gray and malleable iron foundries	Finishing	Area	0.32	1.59	0.73	1.67			0.83	Weighing
122	Phee et al., 1997	1996	Cast of Metals	Gray and malleable iron foundries	Melting	Personal	0.78	1.19	0.96	1.35			1.00	Weighing
123	Phee et al., 1997	1996	Cast of Metals	Gray and malleable iron foundries	Molding	Personal	0.38	1.54	0.85	1.58			0.94	Weighing
124	Phee et al., 1997	1996	Cast of Metals	Gray and malleable iron foundries	Shakeout	Personal	0.16	5.36	1.2	3.11			2.28	Weighing
125	Phee et al., 1997	1996	Cast of Metals	Gray and malleable iron foundries	Finishing	Personal	0.53	3.43	1.28	2.03			1.64	Weighing
126	Phee et al., 1997	1996	Cast of Metals	Gray and malleable iron foundries	Melting	Area	0.23	0.89	0.45	2.62			0.72	Weighing
127	Phee et al., 1997	1996	Cast of Metals	Gray and malleable iron foundries	Molding	Area	0.08	3.94	0.41	3.18			0.80	Weighing
128	Phee et al., 1997	1996	Cast of Metals	Gray and malleable iron foundries	Shakeout	Area	0.31	0.94	0.56	1.57			0.62	Weighing
129	Phee et al., 1997	1996	Cast of Metals	Gray and malleable iron foundries	Finishing	Area	0.06	0.82	0.23	3.43			0.49	Weighing
130	KWCWS, 2014	2011	Heavy construction	Construction of bridges, tunnels and railways	Underpass constructing	Area	0.061	0.114			0.093		0.09	Weighing
131	Yoo et al.,2003	2001	Heavy construction	Construction of bridges, tunnels and railways	Tunnel constructing worker	Personal		5.91	0.46	2.69			0.75	Weighing
132	Yoo et al.,2003	2001	Heavy construction	Construction of bridges, tunnels and railways	Drilling	Personal		0.77	0.35	2.34			0.50	Weighing
133	Yoo et al.,2003	2001	Heavy construction	Construction of bridges, tunnels and railways	Pay loader operating	Personal		4.59	1.08	3.11			2.06	Weighing
134	Yoo et al.,2003	2001	Heavy construction	Construction of bridges, tunnels and railways	Pay loader operating	Personal		4.86	2.46	1.92			3.04	Weighing
135	Yoo et al.,2003	2001	Heavy construction	Construction of bridges, tunnels and railways	Shotcrete pouring	Personal		4.82	2.21	1.72			2.56	Weighing
136	Yoo et al.,2003	2001	Heavy construction	Construction of bridges, tunnels and railways	Dump truck driving	Personal		0.86	0.38	3.01			0.70	Weighing
137	Yoo et al.,2003	2001	Heavy construction	Construction of bridges, tunnels and railways	Heavy machinary operating	Personal		5.91	0.98	1.82			1.17	Weighing
138	Kim et al., 1999	1997	Manufacture of cement, lime and plaster and its products	Manufacture of other refractory ceramic products	Concrete manufacturing	Personal	0.14	0.45	0.26	1.66			0.30	Weighing
139	Oh et al., 1994	1994	Manufacture of ceramic ware	Manufacture of non refractory ceramic building bricks, flooring blocks and similar products	Tile	Personal			0.39	2.73			0.65	Weighing
140	Kim et al., 1999	1997	Manufacture of ceramic ware	Manufacture of other non-structural, non-refractory ceramic ware		Personal	0.06	4.53	0.43	3.29			0.87	Weighing
141	Oh et al., 1994	1994	Manufacture of ceramic ware	Manufacture of other non-structural,non-refractory ceramic were bricks, flooring blocks and similar products	Crushing, milling	Personal			0.45	1.51			0.49	Weighing

No	Reference	Year	KSIC-3digit	KSIC-5digit	Operation	Sample type	Min (mg/m^3)	Max (mg/m^3)	GM (mg/m^3)	GSD	AM (mg/m^3)	SD (mg/m^3)	AMT (%)	Method
142	Oh et al., 1994	1994	Manufacture of ceramic ware	Manufacture of other non-structural,non-refractory ceramic were bricks, flooring blocks and similar products	Mold making	Personal			0.25	2.83			0.43	Weighing
143	Oh et al., 1994	1994	Manufacture of ceramic ware	Manufacture of other non-structural,non-refractory ceramic were bricks, flooring blocks and similar products	Forming, shaping	Personal			0.17	1.09			0.17	Weighing
144	Oh et al., 1994	1994	Manufacture of ceramic ware	Manufacture of other non-structural,non-refractory ceramic were bricks, flooring blocks and similar products	Trimming	Personal			0.48	1.5			0.52	Weighing
145	Oh et al., 1994	1994	Manufacture of ceramic ware	Manufacture of other non-structural,non-refractory ceramic were bricks, flooring blocks and similar products	Glazing	Personal			0.62	2.85			1.07	Weighing
146	Oh et al., 1994	1994	Manufacture of ceramic ware	Manufacture of other non-structural,non-refractory ceramic were bricks,flooring blocks and similar products	Drying, firing	Personal			0.12	5.37			0.49	Weighing
147	Oh et al., 1994	1994	Manufacture of ceramic ware	Manufacture of other non-structural,non-refractory ceramic were bricks, flooring blocks and similar products	Packing	Personal			0.17	1.76			0.20	Weighing
148	Oh et al., 1994	1994	Manufacture of ceramic ware	Manufacture of pottery and ceramic household or ornamental ware	Table ware	Personal			0.29	1.81			0.35	Weighing
149	KWCWS, 2014	2010	Manufacture of ceramic ware	Manufacture of sanitary ceramic ware	Developing						0.067		0.07	Weighing
150	KWCWS, 2014	2010	Manufacture of ceramic ware	Manufacture of sanitary ceramic ware	Shaping						0.054		0.05	Weighing
151	KWCWS, 2014	2010	Manufacture of ceramic ware	Manufacture of sanitary ceramic ware	Forming						0.196		0.20	Weighing
152	Oh et al., 1994	1994	Manufacture of ceramic ware	Manufacture of sanitary ceramic ware	Sanitary ware	Personal			0.88	5.44			3.69	Weighing
153	Kim et al., 2010	2010	Manufacture of ceramic ware	Manufacture of sanitary ceramic ware	Forming	Personal					0.196		0.196	Weighing
154	Kim et al., 2010	2010	Manufacture of ceramic ware	Manufacture of sanitary ceramic ware	Developing	Personal					0.067		0.067	Weighing
155	Kim et al., 2010	2010	Manufacture of ceramic ware	Manufacture of sanitary ceramic ware	Shaping	Personal					0.054		0.054	Weighing
156	Kim et al., 1999	1997	Manufacture of ceramic ware	Manufacture of structural refractory ceramic products	Others(building exterior insulation, polishing and casting subsidiary)	Personal	0.04	0.93	0.29	2.43			0.43	Weighing
157	Oh et al., 1994	1994	Manufacture of ceramic ware	Manufacture of structural refractory ceramic products		Personal			0.4	1.88			0.49	Weighing
158	Kim et al., 1999	1997	Manufacture of coke and briquettes	Manufacture of briquettes and other coal products	Briquets	Personal	0.29	0.88	0.53	1.75			0.62	Weighing
159	Kim et al., 1999	1997	Manufacture of glass and glass products	Manufacture of all other glass and its products n.e.c.		Personal	0.11	1.5	0.42	4.34			1.23	Weighing
160	KWCWS, 2014	2010	Manufacture of other non-metallic mineral products	Manufacture of non-metallic crushed mineral products	Crushing	Personal	0.23	0.369					0.29	XRD
161	KWCWS, 2014	2010	Manufacture of other non-metallic mineral products	Manufacture of non-metallic crushed mineral products	Stone dust compression	Personal	0.044	0.234					0.11	Weighing
162	Kim et al., 2014	2012	Manufacture of other non-metallic mineral products	Manufacture of other stone products	Stone grinding	Personal	0.548	2.657	1.372	1.744	1.567	0.777	1.57	FTIR
163	KWCWS, 2014	2009	Manufacture of other non-metallic mineral products	Manufacture of other stone products	Stone treating	Area					0.621		0.62	XRD
164	KWCWS, 2014	2009	Manufacture of other non-metallic mineral products	Manufacture of other stone products	Cutting, grinding	Area					2.071		2.07	XRD

No	Reference	Year	KSIC-3digit	KSIC-5digit	Operation	Sample type	Min (mg/m^3)	Max (mg/m^3)	GM (mg/m^3)	GSD	AM (mg/m^3)	SD (mg/m^3)	AMT (%)	Method
165	KWCWS, 2014	2009	Manufacture of other non-metallic mineral products	Manufacture of other stone products	Carving	Area					0.102		0.10	XRD
166	KWCWS, 2014	2009	Manufacture of other non-metallic mineral products	Manufacture of other stone products	Surface treatment	Area					0.224		0.22	XRD
167	Kim et al., 1999	1997	Manufacture of other non-metallic mineral products	Manufacture of other stone products	Stone	Personal	0.08	1.26	0.24	2.48			0.36	Weighing
168	Shin, et al., 2002	2000	Mining of coal and lignite	Mining of coal and lignite	Coal mine	Personal	0.2	213.2	5.14	9.1			58.9	Weighing
169	Shin, et al., 2002	2000	Mining of coal and lignite	Mining of coal and lignite	Rock drilling	Personal			1.37	3.3			2.8	Weighing
170	Shin, et al., 2002	2000	Mining of coal and lignite	Mining of coal and lignite	Coal face	Personal			37.7	2.3			53.3	Weighing
171	Shin, et al., 2002	2000	Mining of coal and lignite	Mining of coal and lignite	Transportation	Personal			0.59	3			1.1	Weighing
172	Shin, et al., 2002	2000	Mining of coal and lignite	Mining of coal and lignite	Loading, transportation	Personal			2.89	1			2.9	Weighing
173	Lee & Lee, 1989	1989	Mining of coal and lignite	Mining of coal and lignite	Coal face	Area			6.72	2.38	9.02	6.42	9.02	Weighing
174	Yoon & Lee, 1988	1988	Mining of coal and lignite	Mining of coal and lignite	Drilling	Personal	0.5	30.8	2.8	2.4	4.3	5.4	4.30	Weighing
175	Yoon & Lee, 1988	1988	Mining of coal and lignite	Mining of coal and lignite	Coal cutting	Personal	0.3	93.7	8.3	3.4	16.9	24.2	16.90	Weighing
176	Yoon & Lee, 1988	1988	Mining of coal and lignite	Mining of coal and lignite	Hauling	Personal	0.4	6.1	1.8	1.4	2.4	1.9	2.40	Weighing
177	Yoon & Lee, 1988	1988	Mining of coal and lignite	Mining of coal and lignite	Separating	Personal	0.8	27.8	3.7	2.9	6.8	7.2	6.80	Weighing
178	Yoon & Lee, 1988	1987	Mining of coal and lignite	Mining of coal and lignite	Driller	Personal	0.5	6.7	2.4	2.3	3.1	2.1	3.10	Weighing
179	Yoon & Lee, 1988	1987	Mining of coal and lignite	Mining of coal and lignite	Drilling helper	Personal	0.5	6.7	2.2	2.2	2.7	1.7	2.70	Weighing
180	Yoon & Lee, 1988	1987	Mining of coal and lignite	Mining of coal and lignite	Coal cutting	Personal	2.2	93.3	11.7	3.8	19.3	24.6	19.30	Weighing
181	Yoon & Lee, 1988	1987	Mining of coal and lignite	Mining of coal and lignite	Coal cutting helper	Personal	2.2	134.2	7.9	2.3	10.7	8.7	10.70	Weighing
182	Choi et al., 2000	2000	Mining of iron ores	Mining of iron ores	Rock drilling	Personal			0.47	1.02			0.47	Weighing
183	Choi et al., 2000	2000	Mining of iron ores	Mining of iron ores	Hauling	Personal			0.78	1.58			0.87	Weighing
184	Choi et al., 2000	2000	Mining of iron ores	Mining of iron ores	Loading	Personal			1.57	1.15			1.59	Weighing
185	Choi et al., 2000	2000	Mining of iron ores	Mining of iron ores	Others	Personal			0.56	1.38			0.59	Weighing
186	Choi et al., 2000	2000	Quarrying of stone, sand and gravel	Quarrying of limestone and gypsum	Hauling	Personal			0.15	2.2			0.20	Weighing
187	Choi et al., 2000	2000	Quarrying of stone, sand and gravel	Quarrying of limestone and gypsum	Loading	Personal			0.1	3.4			0.21	Weighing
188	Choi et al., 2000	2000	Quarrying of stone, sand and gravel	Quarrying of limestone and gypsum	Drilling, blasting	Personal			0.34	5.2			1.32	Weighing
189	Choi et al., 2000	2000	Quarrying of stone, sand and gravel	Quarrying of limestone and gypsum	Milling	Personal			1.47	2.4			2.16	Weighing
190	Choi et al., 2000	2000	Quarrying of stone, sand and gravel	Quarrying of limestone and gypsum	Maintenance	Personal					0.42		0.42	Weighing
191	Choi et al., 2000	2000	Quarrying of stone, sand and gravel	Quarrying of limestone and gypsum		Personal	0.25	27.3	1.62	12			5.20	Weighing
192	Choi et al., 2000	2000	Quarrying of stone, sand and gravel	Quarrying of limestone and gypsum		Personal					1.6		1.60	Weighing

Appendix 5. Total crystalline silica concentration of airborne dust samples

No	Reference	Year	KSIC-3digit	KSIC-5digit	Operation	Sample type	N	Min (mg/m^3)	Max (mg/m^3)	GM (mg/m^3)	GSD	AM (mg/m^3)	SD (mg/m^3)	AMT (%)	Method
193	Oh et al., 1994	1994	Manufacture of ceramic ware	Manufacture of pottery and ceramic household or ornamental ware	Table ware	Personal	6			0.0199	4.1			0.054	FTIR
194	Oh et al., 1994	1994	Manufacture of ceramic ware	Manufacture of pottery and ceramic household or ornamental ware	Table ware	Personal	5			0.0263	4.9			0.093	FTIR
195	Oh et al., 1994	1994	Manufacture of ceramic ware	Manufacture of sanitary ceramic ware	Sanitary ware	Personal	8			0.0862	6.2			0.455	FTIR
196	Oh et al., 1994	1994	Manufacture of ceramic ware	Manufacture of structural refractory ceramic products		Personal	7			0.0457	4.2			0.128	FTIR
197	Shin, et al., 2002	2000	Mining of coal and lignite	Mining of coal and lignite	Coal mine	Personal	5	0.001	2.2	0.13	15.1			0.3	FTIR

Appendix 6. Total dust concentration of airborne dust samples

No	Reference	Year	KSIC-3digit	KSIC-5digit	Operation	Sample type	N	Min (mg/m^3)	Max (mg/m^3)	GM (mg/m^3)	GSD	AM (mg/m^3)	SD (mg/m^3)	AMT (%)	Method
198	KWCWS, 2014	2011	Cast of Metals	Steel foundries	Molding	Area	1					0.976		0.98	Weighing
199	KWCWS, 2014	2011	Cast of Metals	Steel foundries	Grinding	Area	1					2.45		2.45	Weighing
200	KOSHA, 2007	2004	Cast of metals	Gray and malleable iron foundries		Personal	9	0.81	1.23			1.02		1.02	
201	Kim et al., 1998	1997	Cast of metals	Gray and malleable iron foundries	Melting	Area	6	0.57	3.35	1.44	1.91			1.78	Weighing
202	Kim et al., 1998	1997	Cast of metals	Gray and malleable iron foundries	Molding	Area	17	0.38	6.7	1.42	1.99			1.80	Weighing
203	Kim et al., 1998	1997	Cast of metals	Gray and malleable iron foundries	Core making	Area	7	0.67	3.16	1.52	1.85			1.84	Weighing
204	Kim et al., 1998	1997	Cast of metals	Gray and malleable iron foundries	Shakeout	Area	9	0.37	7	1.24	2.49			1.88	Weighing
205	Kim et al., 1998	1997	Cast of metals	Gray and malleable iron foundries	Finishing	Area	7	1.03	8.37	3.4	1.95			4.25	Weighing
206	Phee et al., 1997	1996	Cast of metals	Gray and malleable iron foundries	Melting	Area	2	1.14	5.03	2.4	2.85			4.15	Weighing
207	Phee et al., 1997	1996	Cast of metals	Gray and malleable iron foundries	Molding	Area	13	0.34	11.22	1.89	2.48			2.85	Weighing
208	Phee et al., 1997	1996	Cast of metals	Gray and malleable iron foundries	Shakeout	Area	7	0.77	10.81	2.32	2.44			3.45	Weighing
209	Phee et al., 1997	1996	Cast of metals	Gray and malleable iron foundries	Finishing	Area	4	1.29	14.15	3.32	2.91			5.87	Weighing
210	KOSHA, 2007	2004	Cast of metals	Other cast of non-ferrous metals		Personal	1					0.78		0.78	
211	KOSHA, 2007	2004	Cast of metals	Steel foundries		Personal	2					0.967		0.97	
212	KWCWS, 2014	2006	Farming of animals	Farming of horses, sheep and goats	Race ground	Personal	1					5.48		5.48	Weighing
213	KWCWS, 2014	2006	Farming of animals	Farming of horses, sheep and goats	Race ground	Personal	1					5.06		5.06	Weighing
214	KWCWS, 2014	2006	Farming of animals	Farming of horses, sheep and goats	Race ground	Personal	1					13.87		13.87	Weighing
215	KWCWS, 2014	2006	Farming of animals	Farming of horses, sheep and goats	Race ground	Personal	1					15.033		15.03	Weighing
216	Yoo et al.,2003	2001	Heavy construction	Construction of bridges, tunnels and railways	Tunnel constructing worker	Personal	34		71.95	1.47	3.76			3.53	Weighing
217	Yoo et al.,2003	2001	Heavy construction	Construction of bridges tunnels and railways	Drilling	Personal	12		1.2	0.4	1.96			0.50	Weighing
218	Yoo et al.,2003	2001	Heavy construction	Construction of bridges, tunnels and railways	Pay loader operating	Personal	11		25.34	2.85	4.55			8.98	Weighing
219	Yoo et al.,2003	2001	Heavy construction	Construction of bridges, tunnels and railways	Pay loader operating	Personal	9		16.38	3.85	3.39			8.11	Weighing
220	Yoo et al.,2003	2001	Heavy construction	Construction of bridges, tunnels and railways	Shotcrete pouring	Personal	13		25.46	9.37	1.77			11.03	Weighing
221	Yoo et al.,2003	2001	Heavy construction	Construction of bridges, tunnels and railways	Dump truck driving	Personal	15		1.19	0.69	1.49			0.75	Weighing
222	Yoo et al.,2003	2001	Heavy construction	Construction of bridges, tunnels and railways	Heavy machinary operating	Personal	8		10.17	2.39	2.42			3.53	Weighing
223	KOSHA, 2007	2004	Manufacture of basic chemicals	Manufacture of inorganic pigments and other metal oxides	Mixing	Personal	2	0.06	0.41			0.2912		0.2912	
224	KOSHA, 2007	2004	Manufacture of basic iron and steel	Manufacture of ferro-alloys		Personal	3	0.92	1.11			1.02		1.02	
225	KOSHA, 2007	2004	Manufacture of basic iron and steel	Manufacture of Other Basic Iron and Steel n. e. c.		Personal	2	1.407	1.567			1.487		1.49	
226	KOSHA, 2007	2004	Manufacture of basic precious and non-ferrous metals	Manufacture of other basic precious and non-ferrous metals		Personal	4	1.25	2.28			1.74		1.74	
227	KOSHA, 2007	2004	Manufacture of cement, lime and plaster and Its products	Manufacture of cement		Personal	2	0.1103	0.4722			0.2912		0.29	
228	KOSHA, 2007	2004	Manufacture of cement, lime and plaster and Its products	Manufacture of concrete roofing tiles,bricks and blocks	Pouring	Personal	1					0.4815		0.48	
229	KOSHA, 2007	2004	Manufacture of cement, lime and plaster and Its products	Manufacture of concrete roofing tiles, bricks and blocks	Seperating, packing	Personal	2					0.9814		0.98	

No	Reference	Year	KSIC-3digit	KSIC-5digit	Operation	Sample type	N	Min (mg/m^3)	Max (mg/m^3)	GM (mg/m^3)	GSD	AM (mg/m^3)	SD (mg/m^3)	AMT (%)	Method
230	KOSHA, 2007	2004	Manufacture of ceramic ware	Manufacture of ceramic tiles and similar products		Personal	2	1.0818	2.2469			1.6644		1.66	
231	KOSHA, 2007	2004	Manufacture of ceramic ware	Manufacture of industrial ceramic ware		Personal	1					0.7		0.7	
232	KOSHA, 2007	2004	Manufacture of ceramic ware	Manufacture of non refractory ceramic building bricks, flooring blocks and similar products		Personal	1					2.02		2.02	
233	KOSHA, 2007	2004	Manufacture of ceramic ware	Manufacture of other refractory ceramic products		Personal	2	0.895	1.446			1.171		1.171	
234	KOSHA, 2007	2004	Manufacture of ceramic ware	Manufacture of pottery and ceramic household or ornamental ware		Personal	1					10		10.0	
235	Oh et al., 1994	1994	Manufacture of ceramic ware	Manufacture of non refractory ceramic building bricks,flooring blocks and similar products	Tile	Personal	14			0.63	6.4			3.53	Weighing
236	Oh et al., 1994	1994	Manufacture of ceramic ware	Manufacture of other non-structural,non-refractory ceramic were bricks,flooring blocks and similar products	Crushing, milling	Personal	10			1.75	2.8			2.97	Weighing
237	Oh et al., 1994	1994	Manufacture of ceramic ware	Manufacture of other non-structural,non-refractory ceramic were bricks,flooring blocks and similar products	Weighing, mixing	Personal	6			1.25	2.36			1.81	Weighing
238	Oh et al., 1994	1994	Manufacture of ceramic ware	Manufacture of other non-structural,non-refractory ceramic were bricks, flooring blocks and similar products	Mold making	Personal	3			0.37	1.53			0.41	Weighing
239	Oh et al., 1994	1994	Manufacture of ceramic ware	Manufacture of other non-structural,non-refractory ceramic were bricks, flooring blocks and similar products	Forming, shaping	Personal	16			0.91	4.36			2.69	Weighing
240	Oh et al., 1994	1994	Manufacture of ceramic ware	Manufacture of other non-structural,non-refractory ceramic were bricks, flooring blocks and similar products	Trimming	Personal	9			1.21	4.08			3.25	Weighing
241	Oh et al., 1994	1994	Manufacture of ceramic ware	Manufacture of other non-structural,non-refractory ceramic were bricks, flooring blocks and similar products	Glazing	Personal	5			0.77	2.79			1.30	Weighing
242	Oh et al., 1994	1994	Manufacture of ceramic ware	Manufacture of other non-structural,non-refractory ceramic were bricks, flooring blocks and similar products	Drying, firing	Personal	6			0.46	6.75			2.85	Weighing
243	Oh et al., 1994	1994	Manufacture of ceramic ware	Manufacture of other non-structural,non-refractory ceramic were bricks, flooring blocks and similar products	Sand balsting	Personal	4			1.24	2.22			1.70	Weighing
244	Oh et al., 1994	1994	Manufacture of ceramic ware	Manufacture of other non-structural,non-refractory ceramic were bricks, flooring blocks and similar products	Packing	Personal	4			0.24	2.06			0.31	Weighing
245	Oh et al., 1994	1994	Manufacture of ceramic ware	Manufacture of pottery and ceramic household or ornamental ware	Table ware	Personal	28			0.68	3.24			1.36	Weighing
246	KWCWS, 2014	2010	Manufacture of ceramic ware	Manufacture of sanitary ceramic ware	Shaping	Area		0.315	3.669			1.776		1.78	Weighing
247	KWCWS, 2014	2009	Manufacture of ceramic ware	Manufacture of sanitary ceramic ware	Forming			0.1518	4.606					1.20	Weighing
248	Oh et al., 1994	1994	Manufacture of ceramic ware	Manufacture of sanitary ceramic ware	Sanitary ware	Personal	12			1.62	3.1			3.07	Weighing

No	Reference	Year	KSIC-3digit	KSIC-5digit	Operation	Sample type	N	Min (mg/m^3)	Max (mg/m^3)	GM (mg/m^3)	GSD	AM (mg/m^3)	SD (mg/m^3)	AMT (%)	Method
249	Oh et al., 1994	1994	Manufacture of ceramic ware	Manufacture of structural refractory ceramic products		Personal	8			1.39	2.04			1.79	Weighing
250	KOSHA, 2007	2004	Manufacture of glass and glass products	Manufacture of all other glass and its products n.e.c.		Personal	1					0.03		0.030	
251	KOSHA, 2007	2004	Manufacture of glass and glass products	Manufacture of all other glass and its products n.e.c.		Personal	2	0.26	1.12			0.69		0.690	
252	KOSHA, 2007	2004	Manufacture of glass and glass products	Manufacture of glass containers blown or pressed		Personal	2					1.97		1.970	
253	KOSHA, 2007	2004	Manufacture of glass and glass products	Manufacture of glass fibers and optical glass		Personal	3	0.36	0.658			0.525		0.525	
254	KOSHA, 2007	2004	Manufacture of glass and glass products	Manufacture of household glassware		Personal	2	0.4848	1.6667			1.0758		1.076	
255	KOSHA, 2007	2004	Manufacture of glass and glass products	Manufacture of laboratory and other industrial glassware	Grinding	Personal	2		1.73			0.842		0.842	
256	KOSHA, 2007	2004	Manufacture of glass and glass products	Manufacture of laboratory and other industrial glassware	Cutting	Personal	2					0.352		0.352	
257	KOSHA, 2007	2004	Manufacture of glass and glass products	Manufacture of plateglass		Personal	2	0.88	1.86			1.37		1.370	
258	KOSHA, 2007	2004	Manufacture of other chemical products	Manufacture of all other chemical products n.e.c.		Personal	2	0.6486	2.4312			1.5399		1.540	
259	KOSHA, 2007	2004	Manufacture of other metal products;metal working service activities	Coating and similar treatment of metals		Personal	1					2.558		2.56	
260	KOSHA, 2007	2004	Manufacture of other metal products;metal working service activities	Manufacture of articles made from metal wires		Personal	2	1.011	6.684			3.8475		3.85	
261	KOSHA, 2007	2004	Manufacture of other metal products;metal working service activities	Manufacture of hand-operated kitchen appliances and metal ware		Personal	2					1.17945		1.18	
262	KOSHA, 2007	2004	Manufacture of other metal products;metal working service activities	Manufacture of metal pressed and stamped products		Personal	2	0.0287	0.5789			0.3038		0.30	
263	KOSHA, 2007	2004	Manufacture of other metal products;metal working service activities	Manufacture of metal sanitary ware		Personal	2	1.74	2.15			1.945		1.95	
264	KOSHA, 2007	2004	Manufacture of other metal products;metal working service activities	Manufacture of other febricated and processed metal products n.e.c		Personal	1					0.029		0.03	
265	KOSHA, 2007	2004	Manufacture of other non-metallic mineral products	Manufacture of abrasive articles		Personal	6	0.14	2.85			1.49		1.49	
266	KOSHA, 2007	2004	Manufacture of other non-metallic mineral products	Manufacture of non-metallic crushed mineral products		Personal	2	0.09	0.27			0.18		0.18	
267	KOSHA, 2007	2004	Manufacture of other non-metallic mineral products	Manufacture of other stone products		Personal	1					0.04		0.04	
268	KOSHA, 2007	2004	Manufacture of other non-metallic mineral products	Manufacture of other unclassified non-metallic mineralsn.e.c.		Personal	1					4.87		4.87	
269	KOSHA, 2007	2004	Manufacture of other non-metallic mineral products	Manufacture of other unclassified non-metallic minerals n.e.c.		Personal	1					3.875		3.88	
270	KOSHA, 2007	2004	Manufacture of other non-metallic mineral products	Manufacture of ready-mixAsphaltconcrete		Personal	2	0.64	1.04			0.84		0.84	
271	KWCWS, 2014	2007	Manufacture of other non-metallic mineral products	Manufacture of non-metallic crushed mineral products	Mixing	Area	1	0.2009	1.1194					0.52	Weighing

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272	KWCWS, 2014	2007	Manufacture of other non-metallic mineral products	Manufacture of non-metallic crushed mineral products	Packing	Area	1	0.4016	3.5847					1.39	Weighing
273	KWCWS, 2014	2010	Manufacture of other non-metallic mineral products	Manufacture of non-metallic crushed mineral products	Heavy machinary operating	Area						0.382		0.38	XRD
274	KWCWS, 2014	2010	Manufacture of other non-metallic mineral products	Manufacture of non-metallic crushed mineral products	Conveyor belt	Area						0.261		0.26	XRD
275	KWCWS, 2014	2010	Manufacture of other non-metallic mineral products	Manufacture of non-metallic crushed mineral products	Heavy machinary operating	Area		0.057	0.072					0.06	
276	KWCWS, 2014	2009	Manufacture of other non-metallic mineral products	Manufacture of other stone products	Stone treating	Area						2.994		2.99	XRD
277	KWCWS, 2014	2009	Manufacture of other non-metallic mineral products	Manufacture of other stone products	Cutting, grinding	Area						14.19		14.19	XRD
278	KOSHA, 2007	2004	Manufacture of parts and accessories for motor vehicles and engines	Manufacture of other parts and accessories for motor vehiclesn.e.c.		Personal	4	0.99	1.55			1.15		1.15	
279	KOSHA, 2007	2004	Manufacture of Plastic Products	Manufacture of other fabricated structural plastic products	Sandwich panel manufacturing	Personal	4	0.145	1.027			0.64		0.640	
280	KOSHA, 2007	2004	Manufacture of precious metals and ornamentations	Manufacture of pecious metals and related articles		Personal	1					0.0364		0.04	
281	KOSHA, 2007	2004	Manufacture of Rubber Products	Manufacture of industrial un-vulcanized rubber products	Blanking	Personal	2	1.24	1.63			1.435		1.435	
282	KOSHA, 2007	2004	Manufacture of structural metal products, tanks, reservoirs and steam generators	Manufacture of other structural metal products		Personal	1					3		3.00	
283	Shin, et al., 2002	2000	Mining of coal and lignite	Mining of coal and lignite	Coal mine	Personal	24	0.49	331.6	18.9	9.4			232.7	Weighing
284	Shin, et al., 2002	2000	Mining of coal and lignite	Mining of coal and lignite	Rock drilling	Personal	5			5.96	4.1			16.1	Weighing
285	Shin, et al., 2002	2000	Mining of coal and lignite	Mining of coal and lignite	Coal face	Personal	10			180.4	1.5			195.9	Weighing
286	Shin, et al., 2002	2000	Mining of coal and lignite	Mining of coal and lignite	Transportation	Personal	4			1.7	5.2			6.6	Weighing
287	Shin, et al., 2002	2000	Mining of coal and lignite	Mining of coal and lignite	Beam construction	Personal	3			7.32	3.4			15.5	Weighing
288	Shin, et al., 2002	2000	Mining of coal and lignite	Mining of coal and lignite	Loading, transportation	Personal	2			2.28	5.2			8.9	Weighing
289	Choi et al., 2000	2000	Mining of iron ores	Mining of iron ores	Rock drilling	Personal	2			0.65	1.06			0.65	Weighing
290	Choi et al., 2000	2000	Mining of iron ores	Mining of iron ores	Loading	Personal	1					2.02		2.02	Weighing
291	Choi et al., 2000	2000	Quarrying of stone,sand and gravel	Quarrying of limestone and gypsum	Hauling	Personal	6			0.54	1.5			0.59	Weighing
292	Choi et al., 2000	2000	Quarrying of stone,sand and gravel	Quarrying of limestone and gypsum	Loading	Personal	4			0.57	3.3			1.16	Weighing
293	Choi et al., 2000	2000	Quarrying of stone,sand and gravel	Quarrying of limestone and gypsum	Drilling, blasting	Personal	2			0.47	1.59			0.52	Weighing
294	Choi et al., 2000	2000	Quarrying of stone,sand and gravel	Quarrying of limestone and gypsum	Milling	Personal	3			3.76	2.6			5.94	Weighing
295	Choi et al., 2000	2000	Quarrying of stone,sand and gravel	Quarrying of limestone and gypsum	Maintenance	Personal	1					11		11.0	Weighing
296	Choi et al., 2000	2000	Quarrying of stone,sand and gravel	Quarrying of limestone and gypsum	Cleaning	Personal	1					222.5		222.5	Weighing
297	KWCWS, 2014	2007	Site preparation and special trade construction for civil engineering and buildings	Brick laying and stone setting works	Marble treating	Area						6.1774		6.18	XRD