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Determinants of Respirable Crystalline Silica Exposure among Sand-stone Workers

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Abstract **Objective**: Our aim was to determine the occupational exposure level for respirable crystalline silica (RCS) and respirable dust (RD) among sandstone workers. **Materials and methods**: This study was a descriptive analysis of the occupational exposure to respirable crystalline silica (RCS) and respirable dust (RD), utilizing personal air sampling from the breathing zone. The samples were collected throughout the 8-h working day: 88 samples were collected from workers performing stone cutting in mines and at home (wetting system), as well as stone chiseling and stone carving (22 samples each). Twenty-two samples were collected of the RD using the Gravimetric method (NIOSH 600), while for occupational exposure, the level of RCS was measured using a NIOSH 7601spectrophotometer. **Results**: Sand-stone workers had a geometric mean occupational exposure to RD of GM 1.84 mg/m^3. The highest respiratory dust (RD) concentration (2.83 mg/m^3) was found among the stone carvers. Those cutting stone at the mines had the next highest GM (2.65 mg/m^3), while the lowest occupational exposure was seen among those chiseling stone(GM 0.9 mg/m^3). The occupational exposure to RCS had a geometric mean of 0.10 mg/m^3. The highest exposure group was for those cutting stone in the mines (GM = 0.14 mg/m^3) followed by those carving stone (GM = 0.10 mg/m^3). The moderate exposure group was for those chiseling stone (GM 0.05 mg/m^3) followed by those cutting stone at home (GM = 0.03 mg/m^3). The low exposure group had a GM of 0.03 mg/m^3 for RCS. We found the quartz silica concentrations of the sandstone used in this area high (≤90%) as was the percentage of quartz silica in the airborne particulates for stone carving (≤71.4% by volume). **Conclusion**: The stone cutting in mines group and the stone carving group reached occupational exposure limits to RCS which exceeded the 0.05 mg/m^3 OSHA PEL. It is essential to prevent such high exposure through engineering controls, by adapting tools and implementing medical surveillance. All groups had a RCS occupational exposure which would warrant medical surveillance as each group exceeded the OSHA action level of 0.0025 mg/m^3.

Keywords: *silica, respirable crystalline silica, respirable dust, pneumoconiosis, sand stone*

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1. Introduction

Occupational exposure to RCS is a well-established hazard in mining, sand-blasting, foundry work, agriculture, and construction [1]. Workers exposed to RD are likely to acquire silicosis, which is a disease caused by the inhalation of dust comprising crystalline silicon dioxide (SiO2), categorized as quartz, cristobalite, or tridymite [2,3]. Silica dust less than 5 µm may be inhaled into the peripheral respiratory tract. Its accumulation in the lungs causes various pathologies, including fibrosis, which in turn permanently diminishes lung capacity and the ability of the lungs to exchange gas. Patients with silicosis often experience fatigue and present shortness of breath. They may also have other conditions such as emphysema, chronic bronchitis, and lung cancer [4,5]. The culmination in silicosis as diagnosis depends on the concentration of silica and the duration of exposure [6]. Australia, Belgium, Canada, Finland, France, Germany, Switzerland, Sweden, the UK, and the USA have a management and protective system to prevent exposure to silica dust. Exposure to silica dust in the USA is limited to (PEL) 0.1 mg/m3 for an 8-h work duration [7,8]. This limit was implemented in 1979 and records reflect a decrease in the number of silicosis incidents. In addition, several developed countries (i.e., the USA and the UK) control silica dust exposure and impose health surveillance guidelines for RSC exposed workers in systematized and actionable protocols [9,10,11]. In Thailand, the law requires medical surveillance of workers exposed to hazardous chemicals, including silica dust [12,13]. In fact, the concentration of RD and RCS is recorded in relatively few work places and the highest risk is frequently found in non-registered establishments. Our objective was to determine the occupational exposure level of respirable crystalline silica (RCS) and respirable dust (RD) among sandstone workers doing various tasks in various settings [14].

1.1. Justification

Silicosis is a dangerous and incurable disease. Since it is a disease that causes permanent damage to the lungs and impairs lung capacity, there are currently no effective treatments. Patients with symptomatic treatment is only palliative. Silicosis is life-threatening and it affects the body, mind, society, and economy; thus, prevention is the solution. In Thailand, silicosis is a major disease among the reported occupational diseases. As there are informal sectors where skilled and non-skilled workers are intensively involved in working with sandstone, being exposed to respirable crystalline silica (RCS) is a real and present hazard. Notwithstanding, there is no information regarding the occupational exposure to RCS among sandstone miners and carvers.

1.2. Objectives

The objectives of this study were to measure the occupational exposure levels of respirable crystalline silica (RCS) and occupational exposure to respirable dust (RD) among sandstone workers.

2. Materials and Methods

2.1. Study Design and Setting

A descriptive study was conducted among the sandstone workers at Nongnamsai and Ladpuakaow, Sikhio District, Nakhon Ratchasima Province, in northeastern Thailand.

2.2. Study Population and Sample

The study population included workers exposed to RCS at work (i.e., stone-cutters in mines, stone-cutters in the cottage industry (wetting system), stone chisellers, and stone carvers. There were 88 subjects in total, representing all the job types and locations. There were 22 reference subjects; non-sandstone workers living in the study area. For inclusion in the study, the participants had to have been exposed to RCS for more than six months and be between 15 and 60 years of age.

2.3. Job Descriptions

Stone-cutters in the mines had to climb into pits 8 to 10m deep to perform their tasks. Workers used a tool adapted from a lawnmower to cut stone (Figure 1A). By comparison, the tasks for those doing stone-cutting at home included bringing stone home from the mines and cutting it into smaller pieces. This process was conducted using large, water-lubricated circular saws to control the dust (Figure 1B).

Stone chiseling included getting stone from the mines and cutting it into smaller pieces at home (Figure 1C). Stone carving then included cutting stone into the desired shapes and patterns, using tools such as chisels, hammers, large nails, and electric cutters. This task was conducted at the selling point to ease the transportation process (Figure 1D). The contacts for the stoneworkers included housekeepers at the resort near the workers' homes.

2.4. Sample Collection

Samples were collected for each task performed by the sandstone workers, according to NIOSH Method 0600 [15] and NIOSH 7601 [16]. Personal breathing zone (PBZ) samples were collected during normal full shifts (typically 8 hours). PBZ samples for respirable particles and silica were collated simultaneously using personal sampling pumps (SKC Inc, series PCXR4; 1.7 lpm) connected to pre-weighed, 5-µm polyvinyl chloride filter, 37-mm polystyrene sampling cassettes. Multifunction ventilation meters (TSI Inc, Velocicalc 9565 were used to periodically measure temperature, relative humidity, and wind speed.

A: Stone cutting in the mines
B: Wet stone-cutting at home
C: Stone chiseling
D: Stone carving

Figure 1. Tasks of sandstone worker

2.5. Measurement of RD and RCS

All samples were analyzed according to the NIOSH Manual of Analytical Methods. RD samples were analysed gravimetrically using NIOSH Method 0600 and NIOSH 7601. Visible absorption spectrophotometry was used for RCS (quartz) at the Bureau of Occupational and Environment Diseases (BOED), Department of Disease Control, Thailand (BOED). For comparisons, OSHA-TWA of 0.05 mg/m^3 and UK-HSE of 0.1 mg/m^3 and ACGIH TLV-TWA of 0.025 mg/m^3 were used. Exposure intensities (high, moderate and low) were classified by GM of RCS concentrations for each task.

Presenting RD and RCS concentrations were performed by mg/m3 and µ/m^3, consecutively. In order to compare and determines the magnitude of work exposures, high, moderate and low exposures were also categorized.

2.6. Ethical Consideration

This study was approved by the Khon Kaen University Ethics Committee in Human Research (HE #581508). Workers were allowed to decline participation at any time during the data collection phase of the study.

3. Results

Sampling of sandstone dust was conducted via personal sampling in groups of sandstone workers as well as the reference group. The sample included 110 individuals, including 68 males (61.8%) and 42 females (38.2%) (Table 1). The majority were male workers who all performed heavy and dangerous tasks. Female workers usually did the chiseling which did not require much movement.

The silica-exposed workers spent between 7 and 8 hours per day for their tasks. None of the workers used appropriate PPE (viz., respirators). The samples were collected between March and June, when temperatures varied between 24 and 26°C in the morning and 34 and 36°C in the afternoon. The temperature prior to and after sampling differed by 6 to 7°C.

The working environment temperature did not differ between tasks. The relative humidity prior to sampling was between 56 and 59 %, but between 62 and 66 % during sampling. The increased temperature resulted in an increase in relative humidity. The wind speed while stone-cutting in the mines and stone-carving averaged 5.76±1.07 m/s and 5.67±0.76 m/s, respectively (Table 2).

3.1. Concentrations of Respirable Dust (RD)

The highest RD concentration (GM 2.83±1.04 mg/m^3), with a maximum concentration of 5.09 mg/m^3 occurred during stone-carving. A similar high RD concentration was found during stone-cutting in the mines (GM of 2.65±0.92 mg/m$^{3)}$. Stone-cutting at home (GM of 1.01±0.42 mg/m$^{3)}$ and stone-chiseling (GM 0.90±0.41 mg/m$^{3)}$ resulted in less exposure to RD. As for the reference group, a GM of 0.37±0.35 mg/m^3 was reported (Table 3). The box plot (Figure 1) revealed that stone-carving and stone-cutting in the mines had similar values. A similar median was seen for stone-cutting at home and stone-chiseling. Thus, the levels of exposure might be divided into three categories; that is, stone carving and stone cutting in the mines were associated with high exposure to RD, while stone-cutting at home and stone-chiseling were associated with medium exposure to RD. Finally, the reference group (essentially non-exposed) had the lowest exposure to RD.

Table 1. Representation of Workers in Each Task

		Stone-cutting in the mines (n=22)	Stone-cutting at home (n=22)	Stone-chiseling (n=22)	Stone-carving (n=22)	Total (n=88)	References (n=22)	Total (n=110)
Sex	Male	20	20	5	19	64	4	68 (61.8%)
	Female	2	2	17	3	24	18	42 (38.2%)
Age (mean, sd)		43±11.37	44±9.28	39±9.28	42±6.57	42±9.73	41±9.68	42±9.69
Hours/day (sd)		7.18±0.79	7.27±0.63	7.59±0.5	8±0.29	7.48±0.64	n/a	n/a
Protective respirator								
Non-users		4	2	0	8	14 (15.9)	n/a	n/a
Non- proper users		18	20	22	14	74 (84.1)	n/a	n/a

Table 2. Working atmosphere in terms of temperature, wind speed, relative humidity

Task	Temperature Prior to Sampling (Celsius)	Temperature After Sampling (Celsius)	Wind Speed Avg. (m/s)	%Relative Humidity Prior to Sampling	%Relative Humidity After Sampling
1. Stone cutting in the mine	26.3 ± 0.46	34.9 ± 0.56	5.76 ± 1.07	57.2 ± 2.14	62.0 ± 2.65
2. Stone cutting at home	26.4 ± 0.35	34.8 ± 1.02	1.50 ± 0.18	59.1 ± 1.63	66.0 ± 1.64
3. Stone chiseling	26.4 ± 0.42	35.4 ± 0.69	1.50 ± 0.16	57.8 ± 1.51	64.7 ± 0.82
4. Stone carving	24.8 ± 0.69	34.1 ± 0.82	5.67 ± 0.76	56.24 ± 1.87	63.9 ± 1.03
5. References	25.9 ± 0.53	34.7 ± 0.71	3.97 ± 0.43	57.36 ± 1.43	64.0 ±1.57

Table 3. Occupational exposure to respirable dust (RD) using air concentrations of RD

Task	Number of samples	GM (mg/m^3)	Min (mg/m^3)	Max (mg/m^3)
All job titles	88	1.84±1.02	0.31	5.09
1. Stone- carving	22	2.83±1.04	1.56	5.09
2. Stone- cutting in the mines	22	2.65±0.92	1.39	4.55
3. Stone- cutting at home	22	1.01±0.42	0.31	1.86
4. Stone- chiseling	22	0.90±0.41	0.49	1.88
5. References	22	0.37±0.35	0.05	1.3
Total	110	1.19±1.22	0.05	5.09

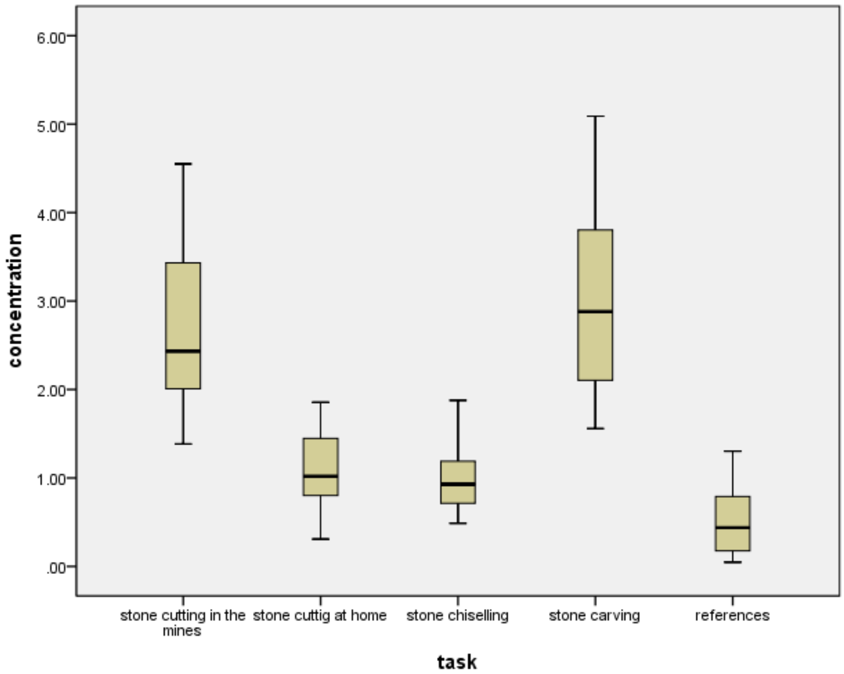

Figure 2. Box plot of respirable dust concentration

When the sample was compared to the standard values for RD (Table 4), the group that had the highest concentration of dust were tasks in mines. Samples collected from stone-carvers revealed an exposure exceeding the OSHA standard limit of 5 mg/m^3 at 4.5% and the ACGIH standard limit of 3 mg/m^3 at 45.5%. Samples of such workers were also in excess of the ACGIH standard limit of 3 mg/m^3 as high as 36.4%. Stone-cutting at home and stone-chiseling were not associated with exposures exceeding the standard limits.

3.2. Occupational Exposure to Respirable Crystalline Silica (RCS) Using Air Concentrations of RCS

From the analysis of each task as well as the standard values, the results revealed that stone-carvers were exposed to a maximum RCS of 3640 µ/m^3; their geometric mean (GM) was 107 µ/m^3, which was lower than for stone-cutting in the mines (GM 141 µ/m^3). Air samples collected while stone-carving also had the highest percentage of SiO_2; as high as 71.4 % of quartz. In addition to occupational exposure to RD, stone-cutting in the mines and stone-carving resulted in an occupational high exposure to RCS. By comparison, stone-chiseling and stone-cutting at home resulted in much lower exposure than was found among stone-cutting in the mines and stone-carving. The references showed quite a high concentration of RCS—close to that found for stone-chiseling (GM 30 µ/m^3) (Table 5).

When the RCS concentration was compared to the standard values (Table 6), almost all air samples taken during stone-cutting in the mines had high concentrations of RCS that exceeded the standard occupational exposure limits. Some air samples taken from the other tasks also had values that exceeded the RCS concentrations for the standard occupational exposure limits. RCS concentrations from the references also had some that exceeded the RCS concentrations.

Table 4. Number of RD concentrations exceeded the standard occupational exposure limits

Task	N	OSHA/ >5 mg.m^{-3}	ACGIH >3 mg.m^3
1. Stone cutting in the mine	22	1 (4.5)	10 (45.45%)
2. Stone carving	22	0	8 (36.36%)
3. Stone chiseling	22	0	0
4. Stone cutting at home	22	0	0

Table 5. Occupational exposure to respirable crystalline silica (RCS) using air concentrations of RCS

Task	Number of samples	RCS, μg/m^{-3}			% SiO_2 quartz		
		GM±GSD	Min	Max	GM±GSD	Min	Max
All job titles	**88**	98±530	10	3640	5.42±10.75	0.15	71.4
1 Stone-cutting in the mines	22	141±103	20	350	6.24±4.38	1.03	15.7
2. Stones-carving	22	107±984	10	3640	11.40±19.42	0.36	71.4
3. Stones-chiseling	22	45±5	10	210	2.11±2.91	0.20	11.9
4. Stone-cutting at home	22	27±36	10	150	1.84±3.34	0.15	12.2
5. Reference	22	30±27	10	120	1.21±2.16	0.03	9.34
Total	110	58±380	10	3640	4.56±9.76	0.03	71.36

Table 6. Proportions of samples exceeding RCS standard occupational exposure limits.

Task	NW	UK HSE-WEL >0.1 mg.m^3	OSHA-PEL >0.05 mg.m^{-3}	ACGIH-TLV >0.025 mg.m^3
1. Stone-cutting in the mines	22	17 (77.27%)	20 (90.90%)	21 (95.50%)
2. Stone-carving	22	4 (4.5)	12 (45.45%)	12 (45.45%)
3. Stone-chiseling	22	6 (27.27%)	8 (36.36%)	16 (72.72%)
4. Stone-cutting at home	22	3 (13.64%)	11 (50%)	10 (45.45%)
5. References	22	2 (9.09%)	8 (36.36%)	11 (50%)

When levels of exposure were considered in the current study, workers who performed stone-cutting in the mines and stone-carving had the highest occupational exposure to RCS (i.e., GM 0.12±0.71 mg/m^3; 0.14 mg/m^3 for stone-cutting in the mines and GM 0.1 mg/m^3 for stone-carving): categorized as high exposure. Moderate exposure to RCS workers included those performing stone-chiseling and stone-cutting at home (average occupational exposure was GM 0.04±0.045 mg/m^3; GM 0.05 mg/m^3 for stone-chiseling and GM 0.03 mg/m^3 for stone-cutting).

Finally, the low exposure group included the references that had an average concentration of RCS of GM 0.03±0.048 mg/m^3 (Table 7).

Table 7. Levels of Occupational Exposure to RD and RCS

Exposure Group	Number of samples	RD (mg/m^3)		RCS (mg/m^3)	
		GM±GSD	Max	GM±GSD	Max
High	44	2.72±0.97	5.09	0.12±0.71	3.64
Moderate	44	1.02±0.41	1.88	0.04±0.045	0.21
Low	22	0.37±0.35	1.3	0.03±0.048	0.12

4. Discussion

In this study, the occupational exposure to RCS and RD were determined using the NIOSH method. The method of air sampling was well-controlled and met the the prevailing standards. Some atmosheric factors during sampling might, however, have influenced migration of airborne dust and affect the concentrations of RCS and RD.

The main findings of this study showed that the sandstone workers stone-cutting in mines, carving and cutting at home (using a wet system), and chiseling were exposed to high concentrations of RCS and RD. Considering exposure to RCS, the workers performing carving and cutting in mines had the highest exposure (GM 0.12 mg/m^3); twice the OSHA-PEL, and quadruple the ACGIH-TLV and Thai-PEL [17]. These high concentrations might be because while rock was being cut in the mines, the terrain was mountainous and the wind speeds high. Research has demonstrated that working in windy locations is associated with a greater risk of developing silicosis [18]. In addition, workers stone-cutting in mines and carving using electric cutters had greater exposure than those using hard tools. Electric cutters produced very small particulate diameters and dispersed them into the air for workers to breathe [19].

The respective RCS concentration and % SiO_2 of sandstone workers was greater than those farming sandy, sandy loam, and clayey soils where respirable quartz concentrations and %quartz range between GM 31.1-31.7 mg/m^3 and 13.6-14.3%, respectively [20]. By way of comparison, Archer et al., 2002 reported the percentage of silica levels (mean 34.7%) among farm workers in eastern North Carolina and it was higher than our study [21]. Linch, 2002 and Mohammadya et al., 2013 reported that construction workers and Iranian industrial workers were exposed to very high concentrations of RCS (0.26-3.3 mg/m^3 and 125-318 μg/m^3, respectively) while concrete blasting, sand blasting, and stone cutting, which are higher levels than we recorded [22,23]. However, when tasks are similar (i.e., stone cutting), the RCS concentration was found to be high.

For workers classified as having moderate RCS exposure (stone-cutting at home and chiseling; GM 0.04 mg/m^3), the lower concentration may be because of the water lubricant system, which resulted in much less dust dispersion. A study showed that dust concentrations could be reduced by more than 10 times or 79% using this technique [24]. When considering chiseling, most workers used manual techniques resulting in much less dust.

Surprisingly, references had relatively high average RCS (0.03 mg/m^3) even though they did not work sandstone. Moreover, some air samples had detectable RCS concentrations that exceeded the new OSHA standard limit (2016) (as high as 36.4%), indicating a significant environment exposure [25]; possibly leading to pneumoconiosis [26] or a risk of abnormal findings on ILO radiographs [27]. In addition, exposure to RCS or RD could cause a decline in FEV_1 [28]. Two studies reported a high prevalence of pneumoconiosis or abnormal radiographs compatible with the ILO radiograph classification and FEV1 declined among stone-cutters in mines and carvers [29].

In the current study, workers were exposed to RCS levels that exceeded the action level of the OSHA standard limit (0.025 mg/m^3) over a period of more than 30 days in a year. Those working with sandstone and people living in the vicinity of sandstone work should be enrolled in a medical surveillance program for pneumoconiosis. Medical surveillance guidelines for RSC-exposed workers include physical examination, respiratory symptoms questionnaire, chest radiographs, and spirometry.

In addition, we observed that none of the workers did wore appropriate respirators and that they were not well-protected from being exposed to RCS.

5. Conclusion

The current study revealed that quartz was the only silicate mineral identified. Workers who performed stone-cutting in mines and carving were exposed to high RCS concentrations that reached occupational exposure limits. Similar findings were found among workers classified as having moderate RCS exposure (who performed stone-cutting at home (using a water lubricated system) and chiseling), where their exposure exceeded standard occupational exposure limits and each group was exposed to RCS levels that exceeded the OSHA action level of 0.025 mg/m^3.

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Recommendations

Engineering controls: Engineering controls could include modified machinery, which would produce less dust [30].

Personal protective equipment (PPE). Workers exposed to RCS concentrations < 0.5 mg/m^3 should use a protective device with an APF of 10 (assigned protection factor), a disposable half mask–particle filter. The filter has a filter efficiency for N95, R95 and P95 particle sizes. Stone-carvers exposed to RCS > 0.5 mg/m^3, should use a respirator with an APF of 40. These include a full-face mask and particle filter for N100, R100, and P100.

Medical surveillance program. A medical surveillance program should be conducted among all persons exposed sandstone dust. The sandstone workers should have their health checked prior to starting their jobs, as well as questioned on their previous occupation and respiratory conditions. They should, moreover, undergo an annual spirometry and/or chest radiograph if certain criteria are met. Currently, in Thailand there is no specific medical surveillance program for workers exposed to RCS.

Statement of Competing Interests

The author has no competing interests.

List of abbreviations

ACGIH = American Conference of Governmental Industrial Hygiene

AIOH = Australian Institute of Occupational Hygienists

FEV1 = Forced expiratory volume in 1 second

ILO = International Labor Organization

NIOSH = National Institute for Occupational Safety and Health

OEL = Occupational Exposure Limit

OSHA = The Occupational Safety and Health Administration

PEL = Permissible Exposure limit

RCS = Respirable Crystalline Silica

RD = Respirable Dust

WHO = World Health Organization

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