

Assessment of Occupational Exposure to Dust and Crystalline Silica in Foundries

Ali Omidianidost¹, Mehdi Ghasemkhani¹,
Mansour R. Azari², Farideh Golbabaee¹

¹ Department of Occupational Health, School of Public Health, Tehran University of Medical Sciences, Tehran, Iran, ² Department of Occupational Health, School of Public Health, Shahid Beheshti University of Medical Sciences, Tehran, Iran

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Correspondence to: Ghasemkhani M

Address: Department of Occupational Health,
School of Public Health, Tehran University of
Medical Sciences, Tehran, Iran

Email address: ghasemkh@tums.ac.ir

Background: The term "crystalline silica" refers to crystallized form of SiO₂ and quartz, as the most abundant compound on the earth's crust; it is capable of causing silicosis and lung cancer upon inhaling large doses in the course of occupational exposure. The aim of this study was to assess occupational exposure to dust and crystalline silica in foundries in Pakdasht, Iran.

Materials and Methods: In this study, airborne dust samples were collected on PVC filters (37 mm diameter, 0.8 mm pore size), by using a sampling pump and open face cyclone at a flow rate of 2.2 l/min for a maximum volume of 800 liters. For determining crystalline silica spectrometry was used according to the National Institute of Occupational Safety and Health (NIOSH) method No. 7601 for analysis of samples.

Results: Results showed that crystalline silica concentration was higher than NIOSH and the American Conference of Government Industrial Hygienist (ACGIH) allowed extent (0.025 mg/m³). Concentration of crystalline silica was 0.02-0.1 mg/m³. Total dust concentration average was higher than the allowed extent by Permissible Exposure Limit (PEL) of the Occupational Safety and Health Administration (OSHA).

Conclusion: It is essential to take necessary measures to control crystalline silica dust regarding the fact that 50% of workers are exposed to higher than the allowed extent.

Key words: Occupational; Exposure; Crystalline silica, Dust

INTRODUCTION

Workers of all industrial and agricultural sectors are at risk of work-related illnesses; after identification and evaluation of harmful factors, optimization of the work environment as well as the controlling processes to prevent the adverse impacts of harmful factors is the most important objective. In the 1980s, there was an estimated 1.7 million US workers exposed to crystalline silica outside of the mining industry (1). The term crystalline silica refers to crystallized form of SiO₂ known as quartz, cristobalite or tridymite; it is the most abundant compound on the earth's crust capable of causing silicosis and lung cancer upon inhaling large doses in course of occupational

exposure (2). The International Agency for Research on Cancer (IARC), recently reviewed the epidemiologic studies of lung cancer and occupational exposure to crystalline silica, and categorized the crystalline silica in the form of quartz and cristobalite as group 1 carcinogen (3). A worker may develop one of three types of silicosis: chronic silicosis, accelerated silicosis and acute silicosis depending on the cumulative dose of respiratory crystalline silica (4). Silicosis, usually a nodular pulmonary fibrosis, is a disease mostly associated with exposure to respiratory crystalline silica. Although, the reported mortality associated with silicosis has declined over the

past several decades, 300 silicosis-associated deaths still occur each year in the US (5). In nature, the alpha form of quartz is the most common form of crystalline silica (6); approximately 100,000 are exposed to a level two or more times greater than the National Institute of Occupational Safety and Health -Recommended Exposure Limit (NIOSH-REL) of 0.05 mg/m^3 (7). One of the most dangerous chemical factors causing the most significant work related illness attributed to silica is a chemical compound that is an oxide of silicon namely SiO_2 ; a colorless, odorless, incombustible solid with a 1600°C melting point (8). In a study conducted by Yassin et al, from 1988 to 2003 in the USA for high risk industries, the least level of exposure to silica was reported to be 0.017 mg/m^3 and the highest value was equal to 0.166 mg/m^3 ; however, it has had a descending trend in recent years (9). Crystal silica exists in many industries such as cement, glass, concrete, ceramic, brick, pottery, foundry, and sandblasting industries (10, 11). Silica in its crystalline form is intensely fibrogenic, highly toxic and associated with autoimmune disorders such as systemic sclerosis (11). It has been shown that an excess of laryngeal cancer occurred in workers exposed to silica dust (12). In a study, Cassidy et al. showed that occupational exposure to crystalline silica was associated with an increased risk of lung cancer (13). Parks et al. suggest that crystalline silica exposure may promote the development of systemic lupus erythematosus in some individuals (14). In another study carried out by Rees and Weiner, 81 foundry workshops in South Africa were examined for dust assessment and spread of pneumoconiosis; the results indicated that the dust value was evaluated and measured only every three years or more in twenty foundry workshops (24%). Lack of control of dangerous dust was obvious in nine studied workshops. Prevalence of silicosis was 0-10.3%; this study offered such satisfactory documents regarding neglecting occupational hygiene at foundries (15). The American Conference of Government Industrial Hygienist - Threshold Limit Values (ACGIH -TLV) for crystalline silica (as α quartz) is 0.025 mg/m^3 Time Weighted Average

(TWA) for up to an 8-hour workday (16). The Occupational Safety and Health Administration- Permissible Exposure Limit (OSHA-PEL) for respirable dust containing silica in general industry is inversely weighted by the proportion of silica in the sampled dust and determined by the formula: $(10\text{mg/m}^3 \div (\% \text{silica} + 2))$ (17). For comparisons to the OSHA criterion, a PEL is calculated for each sample. Assuming 100% silica, the calculated PEL would be $\approx 0.10 \text{ mg/m}^3$ for an 8-hour TWA. NIOSH recommends minimizing risks for silica exposure to workers exposed at or above the REL by substituting less hazardous materials, using engineering controls to limit exposures; if engineering controls cannot control exposures $< \text{REL}$, using respiratory protection and making medical examinations available to exposed workers are mandatory (18). Foundry workers are potentially exposed to a number of carcinogens. Ahn et al. conducted a study to describe the cancer incidence associated with employment in small-sized Korea iron foundries and to compare those findings to the Korean population. In this study, statistically significant increase in lung cancer was observed in production workers compared to Korea general population and office workers. Also, cancer morbidity of overall cancer, lung cancer and stomach cancer significantly increased with duration of employment at 10 and more years comparing to the general Korean population. These findings suggest a causal association between exposure to carcinogens in foundry work and cancer (19). In a 29-year cohort study, Zhang et al. assessed all those employed for more than one year during January 1, 1980 to December 31, 1996 and all members of the cohort were followed-up to December 31, 2008. A total of 2009 workers of an automobile foundry in Shiyan who were exposed to silica dust were evaluated. Results of their cohort study indicated that foundry workers still face a high risk for developing silicosis under work conditions (20). Inhalation of silica dust is hazardous for health. When the sand particles splash decompose, and reach the lowest parts of the respiratory system and can cause silicosis and lung cancer. Azari et al. assessed 10 job categories at workshops

in eastern Tehran; the average density of crystal silica in all industries was above the limit of occupational contact (0.05 mg/m³) recommended by committee of hygiene. Maximum silica density was related to the foundry industry among 10 industries with 0.4 mg/m³ (21). Silicosis is the most important occupational pulmonary illness due to continuous inhalation of dust containing crystal silica, in which the lung tissue is damaged and the ability of oxygenation decreases (18). A wide variety of laborers in various industries are exposed to crystal silica (22, 23).

One of the most significant industries in this regard is foundry castings, in which laborers are exposed to silica dust constantly. The aim of this study was to assess occupational exposure to total dust and crystalline silica in foundries of Pakdasht, Iran.

MATERIALS AND METHODS

A total number of 82 workshops were assessed, which had 417 workers. We chose 22 peripheral samples. Sampling among the recognized workshops was performed. Sampling and determination of free silica within total dust were conducted based on the method 7601 of NIOSH (24). Sampling equipment included sampling pump SKC LTD, TX 44-224 model, open face cyclone, and PVC filter with diameter of 37 mm and 8.0-micron pore size. In order to eliminate humidity, filters were placed at least 24 hours before and after sampling inside desiccators. Flow of the sampling pump was set at 2.2 liters per minute. Daily laborers worked eight-hour shifts with identical working circumstances at all days. Sampling was carried out and at the end the filter samples were transferred to the laboratory and after reposing inside a desiccator, they were weighed and then density of general dust (mg/m³) was assessed based on the below formula.

$$C = \frac{(W_2 - W_1) \times 10^3}{t \times Q}$$

C: Dust concentration in the air in mg/m³

W1: Filter's weight before sampling in milligrams

W2: Filter's weight after sampling in milligrams

t: Time of sampling in minutes

Q: Amount of sampling pump's flow in liters/minute (with correction of sampling air capacity over capacity in standard situation)

In compliance with the regulation of NIOSH, the spectrophotometric method of Visible Absorption, which is reliable to decompose the samples, was utilized as to determine visible free silica (quartz) in dust samples. In order to measure the value of free silica, the standard samples of quartz were provided and the curve of standard calibration was drawn. Afterwards, we analyzed the unknown samples in a spectrophotometer device with a wavelength of 420 nm and the quartz value was obtained based on mg/m³. At the end, the obtained amounts were compared with the recommended standard amounts.

RESULTS

To compare the total dust and crystalline silica concentration, biased variance analysis was used by separation of different foundry projects. The results showed that crystalline silica concentration was the highest in aluminum processing workshops and workers of workshops in which cast iron, brass, and aluminum were processed simultaneously. Brass had the lowest amount among other processes and crystalline silica concentration was higher or equal to the standard level of ACGIH and NIOSH in all processes (0.025 mg/m³)(Table 1).

Table 1. Total dust and crystalline silica's standard deviation and average at different foundries

Foundry projects	Total dust Concentration (mg/m ³)				Crystalline silica's Concentration (mg/m ³)			
	Min	Max	Mean	SD	Min	Max	Mean	SD
Cast iron	0.02	3.20	1.79	1.007	0.001	0.23	0.04	0.07
Brass	1.02	2.50	1.70	0.72	0.01	0.04	0.025	0.017
Aluminum	2.36	2.36	2.30	-	0.10	0.10	0.10	-
Cast iron, brass & aluminum	1.16	2.30	1.77	4.54	0.001	0.19	0.19	0.08

T-test was used to compare total dust and crystalline silica concentration and assess their interaction and the

results showed that use of fan caused the crystalline silica and total dust concentration to decrease significantly (Table 2).

Table 2. Total dust and crystalline silica's average and standard deviation in fan reaction and usage separately to general conditioning at foundries (mg/m³).

	Total dust		Crystalline silica's	
	Concentration (mg/m ³)		Concentration (mg/m ³)	
General Conditioning	Mean	SD	Mean	SD
Suitable	1.39	0.83	0.01	0.009
Unsuitable	2.04	0.75	0.07	0.07

DISCUSSION

Foundries with fewer than 10 people are foundries that work in a traditional way with rotating or ground forges, and compared to the larger foundries, have lower activity and capacity. The degree of silica dust diffusion is more at large foundries due to their production capacity. The present study compared the occupational exposure in different foundries in terms of density level of crystal silica in 22 different small foundry workshops selected, including 10 cast, three brass, one aluminum and four combined workshops (containing three previous processes). Among the abovementioned workshops, 22 environmental samples of total dust were collected from a height of 1.5 meters close to the breathing zone. Comparison of dust density of crystal silica with different processes showed that the density of free silica at the aluminum plant was more than the others and the combined process ranked second, and the brass processing plant was the least; in addition, in all the processes (brass, aluminum and combined), density of crystal silica was less or equal to the authorized limit of NIOSH and ACGIH (0.025 mg/m³) (25). Since in some brass foundry processes such units, as molding, sandblasting, and sand processing do not exist for framing, consequently, the accumulation of crystalline silica dust in the workshop were low. In combined casting, due to the variety and volume of produced pieces as well as use of different sands, an accumulation of dust in the workshop is observed that will

result in higher density of crystalline silica. The density of free silica dust was 50% higher than the recommended limit by NIOSH and ACGIH (0.025 mg/m³) in half of the workshops (25). Comparing the concentration of free silica dust towards the fan installed on the windows showed that the use of a fan ventilation leads to reduced density of total dust and crystalline silica, which was significant. In addition, in terms of the area of the production hall's, in the workshops having production areas larger than 500 square meters, the density of crystalline silica and total dust was greater than the plants with production areas less than 500 square meters; this may be due to more activity of the workshops and the higher number of employees and the volume of produced items. The outcomes indicate that the total amount of dust and the density of free silica in the work environment of small foundries were above the allowed limit.

Results showed that crystalline silica concentration is maximum and minimum in aluminum and brass foundries, respectively. Total dust concentration including silica was higher than the recommended PEL by OSHA organization in all processes. Crystalline silica's concentration and total dust in units with suitable general conditioning was lower than the processes without suitable air conditioning. Results indicate that there is a risk for crystalline silica pollution in the breathing air in the small foundries.

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