Original Article

A Study on Respirable Dust and Crystalline Silica among Construction Workers

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ABSTRACT: *This study aims to determine the Respirable Dust (RD) and Respirable Crystalline Silica (RCS) exposure level for different activities at construction sites. The samples were collected throughout the 8H TWA working day, inclusive 36 personal activities, periodic samples for mixing, cutting and plastering and compliance status among workers in construction sites. Samples were retrieved from the Klang Valley area (Kuala Lumpur and Selangor). In this research, the NIOSH Manual of Analytical Methods (NMAM) 0600 had been used for RD and NMAM 7500 for Respirable Crystalline Silica analysis (RCS-quartz). A quick survey on silica dust monitoring and Personal Protective Equipment (PPE) was done concurrently during data collection. The results indicated around 39.5 % of workers in mixing activity were slightly exposed to RCS-quartz level above the Permissible Exposure Limit (PEL) based on Occupational Safety and Health (Use and Standard of Exposure to Chemical Hazardous to Health) Regulations 2000 (USECHH Regulations). Activity with the highest exposure were mixing, followed by plastering and the lowest was cutting activity.*

Keywords: *Gravimetric Analysis, Respirable Crystalline Silica-Quartz, Respirable Dust, X-ray Diffraction (XRD)*

1.0 INTRODUCTION

Silica is a mineral compound that is composed of one silicon atom and two oxygen atoms (SiO_2) (ACGIH, 2001). Silica exists in several forms, whereby the most common form is crystalline silica, which makes up to 12% of the earth's crust (NIOSH, 2002). The three major forms of crystalline silica are quartz, cristobalite and tridymite. Quartz is the most common form of silica, and it is reasonable to use quartz as the standard because the other forms of silica are usually not present with a significant amount in industrial hygiene samples (Ashley & O'Connor, 2016). This natural substance can be found in rocks, sand, clay and products such as bricks and concrete. Silica was reported as a Group 1 carcinogenic compound by the International Agency for Research on Cancer (IARC, 2008).

Silica dust particles are small enough to penetrate deeply into the lungs when breathed in and are known as Respirable Crystalline Silica (RCS). RCS dust particles are too small to be seen under normal lighting. RCS particle size range of 10 µm or less is harmful to health because particles inhaled are penetrated deeply into the lungs (IARC, 1997). RCS will trap forever in the lung, and its deposition will trigger a chronic inflammatory response and be replaced with scar tissue (fibrosis). The scar will decrease the percentage of oxygen gas exchange known as silicosis disease, and when exposed to a large amount, it will increase the risk of lung cancer in humans (Sato, Shimosato & Klinman, 2018). As crystalline silica has been used in many industries such as cement manufacturing, glass and concrete mixing product manufacturer, sandblasting, ceramic, clay and many construction activities, silica dust is considered an inhalation risk (Omidianidost et al., 2016). Especially the work processes in the construction industry such as cutting, sanding, grinding, blasting or polishing materials is highly exposed and can generate RCS easily.

Malaysia has a lack of information on crystalline silica exposure. This study aims to determine exposure levels of dust and RCS for different activities at the construction site. Furthermore, the difficulty of implementing a control system in the workplace due to constant change of construction activities and work location makes it crucial for this study to determine eligibility and compliance status among exposed workers in construction sites.

The experiment in this study had been carried out based on NMAM 7500 using XRD's machine. It was a versatile and non-destructive analytical technique that reveals detailed structural and chemical information about the crystallography of materials. XRD looks at a crystalline material's characteristic X-ray scattering, or diffraction pattern, which reveals the material's atomic structure. Activities among construction workers were selected in this study, including mixing, plastering and cutting tiles.

2.0 METHOD

2.1 Total Respirable Dust

The respirable dust analysis was measured by using the NIOSH Manual of Analytical Methods (NMAM) 0600. The filters were weighed before and after sampling on a Mettler Microbalance (XP26; Mettler-Toledo, Greifensee, Switzerland) to collect dust weight. Filters with the holders were stored in an environmentally controlled area (20 ± 1 0C and 50 ± 5% relative humidity) for at least 2 hours for stabilization before tare and weighing the post – weight. (2) 3 readings of the pre-weight and post-weight were performed. The difference between the averages of pre-weight and post-weight was the result of the analysis of respirable dust.

2.2 Crystalline Silica-Quartz Measurement (XRD)

NMAM 7500 were used to determine Respirable Crystalline Silica (RCS) exposure, (NIOSH, 2003). The filters were treated and analysed using XRD (Rigaku, Multiflek, Tokyo, Japan) to obtain the RCS-quartz values (NIOSH, 2003). The filters were digested with hydrochloric acid and then ashes in a muffle furnace at 600°C for 2 hours. The ash was then dissolved in 15ml 2-propanol and then filtered on 25mm silver membranes to make them compatible with the 25mm X-ray diffraction auto sampler. Analytical procedures were subjected to quality assurance requirement under MS ISO17025 accreditation program.

2.3 Statistical Analysis

American Industrial Hygiene Association (AIHA) suggested collected data shall be analysed by using IHSTAT - Statistical Analysis of Health & Safety Data.

3.0 RESULTS

3.1 Demographic Data among Constructions Sites Workers

The epidemiological characteristics of the subjects studied are presented in Table 1. The majority of workers were male compared to female and the age range was between 20 and 40 years old. The PPE compliance survey reflected 83.3% of workers wearing a safety helmet and 69.4% wearing safety shoes during working hours. Perhaps surprisingly, only 16.7% of workers did not wear the appropriate mask (surgical mask) and 5.6% wore a glove with the lowest PPE compliance.

Table 1 Demographic Data of Construction Sites Workers

No.	Sample Id	Gender	Work Area	PPE Compliances			
				Safety Helmet	Safety Shoes	Dust Mask	Glove
1	Mixing 1	M	Mixing	/	/	/	No
2	Mixing 2	M	Mixing	/	No	Surgical Mask	No
3	Mixing 3	M	Mixing	/	/	Surgical Mask	No
4	Mixing 4	F	Mixing	/	/	Surgical Mask	/
5	Mixing 5	F	Mixing	/	/	No	No
6	Mixing 6	F	Mixing	/	/	No	No
7	Plastering 1	M	Plastering	/	No	No	No
8	Plastering 2	M	Plastering	/	No	No	No
9	Mixing 7	M	Mixing	No	/	Surgical Mask	/
10	Cutting 1	M	Cutting	/	No	No	No
11	Plastering 3	M	Plastering	/	/	No	No
12	Plastering 4	M	Plastering	/	No	Surgical Mask	No
13	Plastering 5	M	Plastering	/	/	No	No
14	Plastering 6	M	Plastering	/	/	No	No
15	Plastering 7	M	Plastering	/	/	No	No
16	Cutting 2	M	Cutting	/	/	No	No
17	Cutting 3	M	Cutting	/	/	No	No
18	Mixing 8	F	Mixing	/	/	No	No
19	Mixing 9	F	Mixing	/	/	No	No
20	Plastering 8	M	Plastering	/	No	No	No
21	Plastering 9	M	Plastering	/	No	No	No
22	Mixing 10	M	Mixing	/	/	No	No
23	Mixing 11	M	Mixing	/	/	No	No
24	Cutting 4	M	Cutting	No	No	No	No
25	Cutting 5	M	Cutting	/	No	No	No
26	Plastering 10	M	Plastering	/	/	No	No
27	Plastering 11	M	Plastering	/	/	No	No
28	Plastering 12	M	Plastering	/	/	No	No
29	Plastering 13	M	Plastering	No	/	No	No
30	Plastering 14	M	Plastering	/	/	No	No
31	Plastering 15	F	Plastering	No	/	No	No
32	Mixing 12	M	Mixing	/	/	No	No
33	Mixing 13	M	Mixing	/	/	No	No
34	Cutting 6	M	Cutting	No	No	No	No
35	Cutting 7	M	Cutting	No	No	No	No
36	Cutting 8	M	Cutting	/	/	No	No

M = Male, F = Female, PPE = Personal Protective Equipment

3.2 Respirable Dust Exposure Level

The overall results indicated that the exposure levels of respirable dust in all activities were ranged between 0.060-2.419 mg/m3 which is below the Permissible Exposure Limit (PEL) 3.0 mg/m3 as stated in the Occupational Safety and Health (Use and Standard of Exposure Chemical Hazardous to Health) Regulations 2000 (USECHH Regulations). The top range was mixing activity with a minimum of 0.102 and a maximum of 2.419 (Table 2). The higher Arithmetic Means (AM) is shown in the mixing activity at value 0.641 mg/m3 followed by cutting at value 0.471 mg/m3. Meanwhile, the plastering activity was recorded with the lowest AM with a value of 0.306 mg/m3. This study also shows that the mixing activity is ranked as the highest occupational exposure on respirable dust, where the geometric mean GM value is 0.411 mg/m3 (2.696 mg/m3) followed by cutting activities at 0.361 mg/m3 and plastering at 0.249 mg/m3. Detailed results for respirable dust personal exposure of activity are indicated in Table 2.

Table 2 Respirable Dust Personal Exposure by Activity

Activity	N	Range (mg/m^3)		AM	GM	GSD	% ≥ OEL
		Min	Max				
Plastering	14	0.060	0.821	0.306	0.249	1.951	0.000
Mixing	14	0.102	2.419	0.641	0.411	2.696	0.056
Cutting	8	0.101	1.159	0.471	0.361	2.240	0.000

AM: Arithmetic Mean; GM: Geometric Mean; SD: Standard Deviation; GSD: Geometric Standard Deviation

3.3 Respirable Crystalline Silica-Quartz Exposure Level

The finding has shown that the range of silica exposure levels reported was between 0.004 to 0.237 mg/m3. The highest range appears to be mixing activity with a minimum of 0.005 and a maximum of 2.419 (Table 3). The highest AM was reported by mixing activity at the mean value of 0.084mg/m3, followed by plastering at 0.030 mg/m3 and cutting at 0.029 mg/m3. All of these AM values were slightly below PEL 0.1mg/m3. The highest occupational exposure activity to silica was indicated by the mixing activity where the GM value at 0.040 mg/m3 was followed by the cutting activity at 0.026 mg/m3 and the plastering activity with the value 0.016 mg/m3. From Table 3, presuming a similar approach is practised at a different time interval, we may conclude that 39.5% of workers from mixing activity were more likely to be exposed to silica and exceeding the PEL.

Table 3 Respirable Crystalline Silica - Quartz Personal Exposure by Activity

Activity	N	Range (mg/m^3)		AM	GM	GSD	% ≥ OEL
		Min	Max				
Plastering	14	0.004	0.126	0.030	0.016	3.338	4.907
Mixing	14	0.005	0.237	0.084	0.040	3.667	39.483
Cutting	8	0.011	0.037	0.029	0.026	1.580	0.000

3.4 Compliance Status on RD and RCS-Quartz by Activity

Table 2 and Table 3 show descriptive and inferential statistics on 8H TWA personal exposure to respirable dust and RCS-quartz among workers at construction sites. In summary, AM and GM for respirable dust were not significant and far below 3.0 mg/m3 Malaysia's PEL, but for RCS-quartz, the exposure levels were significant as mixing and plastering reporting a results above the PEL (0.1 mg/m3).

By referring to Fig. 1 through Fig. 4, the respirable dust and RCS-quartz exposure level were compared among construction workers and plotted against the log probability, least squares best-fit line and log-normal distribution. In this study, the percentage of Occupational Exposure Limit (OEL) for respirable dust was not significant because only 0.056% of the exposure were likely. With an AM value of 0.641 mg/m3, the amount is much lower compared to 3.0 mg/m3 PEL (Fig. 2). However, the study also shows that approximately 39.483% (Fig. 3) were exposed to an RCS-quartz exposure level of 0.084 mg/m3, which is slightly lower than the PEL of RCS-quartz at 0.1 mg/m3 (Fig.4).

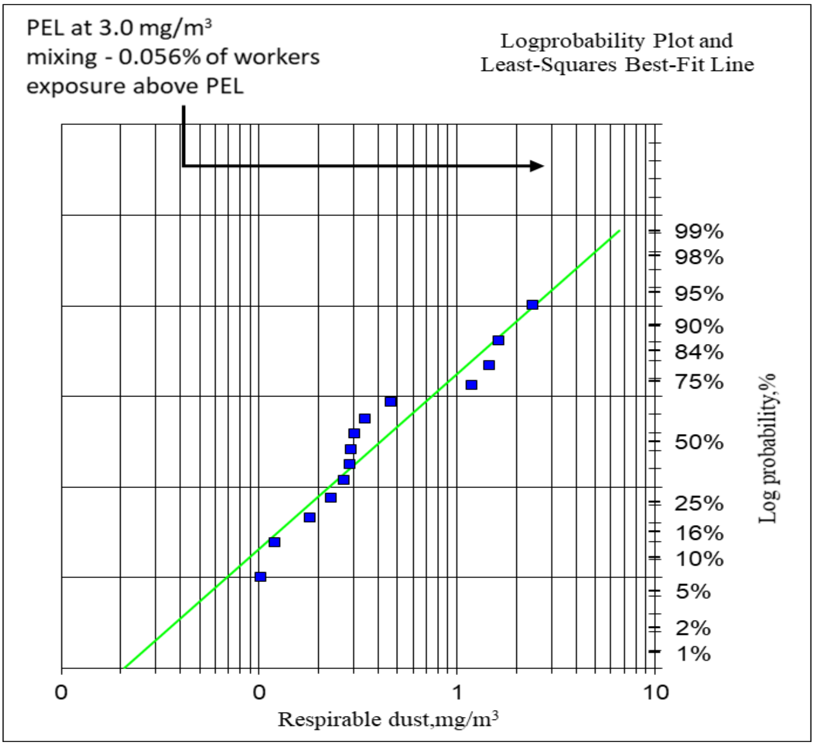

Figure 1 Graph Log Normal Probability Plot and Least-Squares Best-Fit Line for Respirable Dust Exposure Level. PEL by Malaysia USECHH Regulations 2000 is at 3.0 mg/m^3 for Respirable Dust.

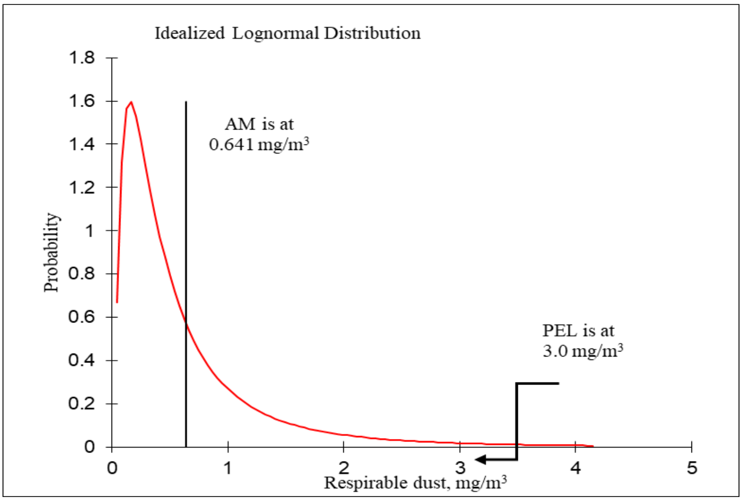

Figure 2 Log Normal Distribution for Respirable Dust Exposure, AM; Estimated Arithmetic Mean. PEL by Malaysia USECHH Regulations 2000 is at 3.0 mg/m³ for Respirable Dust.

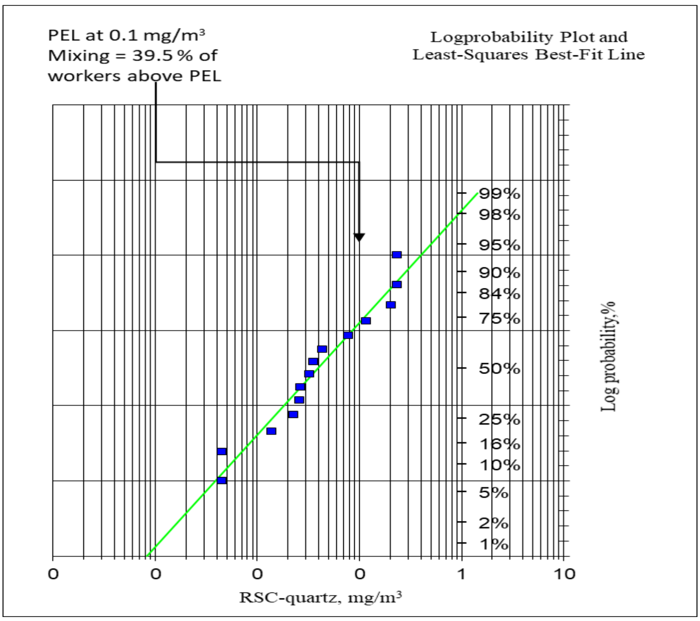

Figure 3 Log Normal Probability Plot and Least-Squares Best-Fit Line for RCS-Quartz Exposure. PEL by Malaysia USECHH Regulations 2000 is at 0.1 mg/m³ for RSC-Quartz.

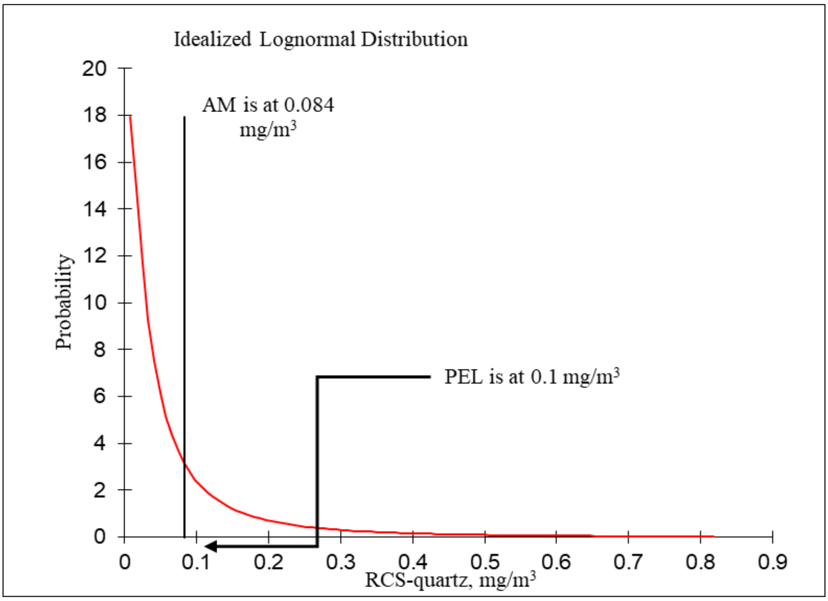

Figure 4 Log Normal Distribution for RCS-Quartz Exposure, AM; Estimated Arithmetic Mean. PEL by Malaysia USECHH Regulations 2000 is at 0.1 mg/m^3 for RSC-Quartz.

4.0 DISCUSSION

The samples in this study were collected at construction sites. The samples for dust and silicon-quartz exposure of this group have not been thoroughly investigated in our country. The sampling was done at two construction sites in the Klang Valley area as these areas were developed by many construction projects. Then, the samples were selected among the three most common activities including mixing, plastering and tiles cutting. As reported, the exposure of silica may cause silicosis with increasing cumulative exposure with duration of exposure (odds ratio = 1.37; 95% confidence interval = 1.14 –1.65) (Cassidy et al., 2007). Therefore, researchers are interested in knowing more about the silica exposure level among Malaysian construction workers.

The highest exposure to respirable dust was identified from the mixing activity (0.641 mg/m3). However, there are no significant dust concentrations discovered above the OEL. This is probably because the activity was performed in an open area thus many movements involved could potentially manipulate the materials that produce dust with and without silica.

Even so, this study shows cutting activity with the second-highest dust exposure for the arithmetic mean and geometric mean, but it was not significant. Similar to the high cutting activity results shown by Yassin et al. (2005) from his data on OSHA, Integrated Management Information System. Among the eight industries, the highest GM value comes from cutting stone and stone products (0.091 mg/m3) compared to other activities such as concrete cutting work (0.073 mg/m3), bridge, tunnel construction (0.070 mg/m3) and stone masonry (0.065 mg/m3). Our data should support more evidence in representing a similar exposure pattern in workers.

In this study, plastering work shows the lowest dust concentration (0.306 mg/m3) compared to mixing (0.641 mg/m3) and cutting (0.471 mg/m3) activities. It was noted that the plasterer uses a water jet pump, which could be the main reason for less exposure of dust throughout the plastering activity. The level of exposure to dust can vary and influence of many factors depending on job duties, type of material, equipment and tools used, environmental conditions and skill level of the workforce.

For RCS-quartz, mixing activity (0.084 mg/m3) has the highest exposure level with 39.08% of this group exposed above the OEL. Yassin et al (2005) stated that 4.8 % of workers are likely to be exposed to silica in plastering work, which is very close to these findings (4.907%).

In this study, the lowest exposure of the silica level was recorded by the cutting activity with the AM value of 0.029 mg/m3, but the percentage of exposure is insignificant (0.000%) due to the small sample size. This result contradicts Mohamed SH, et al. (2018) results which indicate a max, mean silica% found in stone cutting at 48.65%.

Although the findings show a low level of exposure to respirable dust and silica (below PEL), the awareness of construction workers wear PPE for protection was still very low. A surgical mask is available for the workers, but as observed only a few workers were using it. For this activity, respiratory protection must be worn and N95 is suitable for reducing exposures or below the occupational exposure limit, especially for the mixing activity. During the work process, mixing activities will produce large amounts of dust containing silica and these exposures can potentially exceed the occupational exposure limits.

5.0 CONCLUSION

Approximately 39.5% of workers in the mixing operation were overexposed to RCS-Quartz above the PEL. OSHA regulatory efforts are needed to further increase industry compliance with occupational exposure limits by enforcing effective engineering controls and to protect workers from overexposure to crystalline silica. Therefore, it is highly recommended that engineering controls should be in place to prevent the recurrence of high silica exposure. For example, in tiles cutting activity, wet cutting is the most effective method for controlling silica dust generated during the cutting process because when the dust is wet, it is less able to become or remain airborne. In addition, other controls must take into consideration, change in work practices (e.g. implementing worker rotation programs for mixing activity) and issues related to Personal Protective Equipment (PPE).

Appropriate respiratory protection should be used when source controls failed to keep exposures below occupational exposure limits. Workers exposed to Silica should participate in a medical surveillance program and undergo periodic respiratory health evaluations.

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