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Silica Dust Exposure Levels in the Construction Industry in Zambia in Relation to the Permissible Exposure Limit

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ABSTRACT

One of the staple hazards in construction is silica dust which is produced from materials such as concrete, brick, sand, and stones. It causes respiratory diseases like renal diseases, chronic obstructive pulmonary diseases and silicosis when inhaled for a long time or in high levels. Zambia's construction industry recorded symptoms of respiratory diseases which were attributed to exposure to dust by the Occupational Health Safety Institute. Also, there is a high likelihood of an increase in the generation of dust and possible exposure to silica dust from high volumes of construction projects as Zambia prepares to become a middle-income country by 2030. However, it is not known whether silica dust exposure levels were above 0.05mg/m3.Therefore, this paper presents the silica dust exposure levels in relation to Occupational Safety and Health Administration Permissible Exposure Limit of 0.05mg/m3. Fifteen personal samples were collected during work activity for 8hr-Time Weighted Average at a flow rate of 2.2 L/min using a battery-operated Casella Apex2 pump connected through a tubing to a pre-weighted 25-mm, 5-µm pore size polyvinyl chloride filter. Silica dust was analysed using X-ray diffraction. One sample test was used to test for significance and $\rho < 0.05$ and confidence interval of 95% were considered as statistically significant. Silica dust exposure levels were higher than both local and international Occupational Safety Health Administration Permissible Exposure Limit (0.05mg/m^3). Therefore, a combination of effective controls according to the hierarch of controls should be employed to safeguard workers' health and reduce the effects on the projects.

Keywords: Construction; Exposure; Levels; Silica Dust; Zambia

Abbreviations: ACGIH: American Conference of Governmental Industrial Hygienist; AM: Arithmetic Mean; CDC: Center for Diseases Control and Prevention; CV: Critical Value; DF: Degree of Freedom; GM: Geometric Mean; HSE: Health Safety Executive; LEV: Local Exhaust Ventilation; LOQ: Limit of Quantification; NHLS: National Health Laboratory Services; NIOSH: National Institute for Occupational Safety and Health; OSHA: Occupation Safety and Health Administration; OHSI: Occupational Health and Safety Institute; PEL: Permissible Exposure Limit; PVC : Polyvinyl Chloride; REL: Recommended Exposure Limit; RPE: Respiratory Protective Equipment; RCS: Respirable Crystalline Silica; SANAS: South African National Accreditation System; SPSS: Scientific Package for Social Sciences ; TLV : Threshold Limit Values; TWA: Time Weighted Average; WELs: Workplace Exposure Limits; XRD: X-Ray Diffraction

Introduction

Construction industry is considered one of the most hazardous industries. One of the important hazards is crystalline silica dust [1] because when inhaled, may cause symptoms of respiratory diseases such as renal diseases, chronic obstructive pulmonary diseases, tuberculosis and silicosis [2,3]. Silicosis is the most lethal respiratory disease as it has no known cure [4]. Despite this fact, exposure to silica dust in construction is unavoidable because it is contained in some construction staple materials such as concrete, brick, sand and stones [5,6]. When these materials are worked on, they produce silica dust. According to Occupation Safety and Health Administration (OSHA), silica dust exposure levels above 0.05mg/m^3 at 8hr- Time Weighted Average-(TWA) are regarded as harmful as they have potential to af-

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fect workers' health [7]. Silica dust concentration of 0.05mg/m^3 is referred to as Permissible Exposure Limit (PEL). Several countries have recorded silica dust levels above 0.05mg/m^3. In Switzerland, 80% of the silica dust measurements for demolition and reconstruction were above 0.15mg/m^3 and beyond the Threshold Limit Values (TLV) [8]. Finland recorded silica dust exposure levels of 0.53mg/m^3 during dry season [9]. Similarly, in Netherlands, silica dust exposure was 0.5mg/m^3 [10]. In Zambia, silica dust exposure levels the construction workers were exposed to were not known. Yet the industry recorded symptoms of respiratory diseases [11,12]. The respiratory diseases were attributed to exposure to dust by the Occupational Health and Safety Institute (OHSI). Therefore, there is a concern for the silica dust exposure and its negative impact in construction. This is because silica dust affects workers' health, cost projects through lost man-hours, low productivity, hospital bills and compensations. Thus, this paper presents the silica dust levels in the construction industry in Zambia in relation to the OSHA PEL of 0.05mg/m^3.

Some of the construction activities that produce silica dust are surface grinding and finishing, tuck-point grinding, rock breaking, sanding of drywalls, tile cutting, brick and concrete block cutting and abrasive blasting [2]. This is evidenced in the study by Gharpure, et al. [13] where they found that concrete contains 30% crystalline silica using X-ray diffraction. Some of the things that enhance high silica dust exposure levels are dusty working methods, no natural ventilation works, improper use or lack of Respiratory Protective Equipment (RPE), less use of Local Exhaust Ventilation (LEV) and the use of high silica content materials [4,10,13,14]. Different studies have recorded different silica content ranging from 2.2 to 40% [4,10,15]. The higher the silica content in construction materials, the higher the silica dust exposure levels and the higher the likelihood of the workers inhaling levels higher than OSHA PEL of 0.05mg/m^3. There are several international exposure limits for silica dust such as the Occupational Safety and Health Administration Permissible Exposure Limits (OSHA PELs), the HSE Workplace Exposure Limits (WELs), the American Conference of Governmental Industrial Hygienist (ACGIH) Threshold Limit Values (TLVs) and the National Institute for Occupational Safety and Health (NIOSH)Recommended Exposure Limits (RELs). The OSHA PELs are mandatory, exposure legal limits that are enforceable under Occupational Safety and Health Act of the United States of America (USA). The OSHA PEL for respirable crystalline silica in construction industry, is 0.05mg/m^3 in 8-hour TWA. The HSE is a safety and health regulator in Great Britain whose mandate is to prevent workplace accidents and ill-health. The WELs are legal limits which are not supposed to be exceeded. The crystalline silica dust WEL for HSE is 0.1mg/m^3, respirable dust is 4mg/m^3 and total dust is 10mg/m^3 over 8-hour TWA [16]. Despite the WELs being legally binding, they are not supposed to be exceeded. The ACGIH is a charitable scientific organization that advances occupational and environmental health through the recommendations for safe levels of substances.

The recommendations are derived from scientific and toxicological information. Therefore, the ACGIH safe levels are health-based guidelines. The ACGIH TLVs for respirable dust should be below 3mg/m^3 and inhalable dust below 10mg/m^3 over 8-hour TWA respectively [17]. The NIOSH is a research agency under Center for Diseases Control and Prevention (CDC) which is mandated to safeguard the safety and health of workers in USA. The NIOSH RELs concentrations for dust that should not be exceed over an 8 or 10-hour work shift. The NIOSH REL for respirable crystalline silica is 0.05mg/m^3.Comparing the exposure limits for OSHA, ACGIH, NIOSH and HSE, the lowest crystalline exposure limit is OSHA PEL which is 0.05mg/m^3 over 8-hour TWA. Any crystalline silica dust exposure levels above 0.05mg/m^3 are considered a risk to the workers as these levels may have hostile health effects [7]. Consequently, in this research, OSHA PEL of 0.05mg/m^3 was used because Zambia has not yet established the silica dust limit. The legal limit for total dust in Zambia is 1.74mg/m^3 [11,18]. Exposure to silica dust in construction differ from profession to profession and task to task despite working on the same construction sites [1]. Flanagan, et al. [15], found that surface grinding had higher exposure levels of silica dust compared to sacking and patching concrete, concrete cutting, tuck-point grinding, demolition with handheld tools and concrete floor sanding. The average silica concentration in the tasks was 0.11mg/m3 which exceeded the Threshold Limit Value (TLV) of 0.05mg/m^3 [15]. Similarly, Li, et al. [4] found that ten percent of the samples exceeded 0.05mg/m^3 during cement mixing, concrete breaking, and manual demolition.

On the profession, demolition workers were exposed to higher level of silica dust (Geometric Mean -GM of 1.1mg/m^3) which was beyond the Dutch exposure limit of 0.075mg/m^3 [10]. Normahammadi, et al. [2] also found that demolition workers were exposed to silica dust levels more than Occupational Exposure Limit (OEL). The GM was 0.132mg/m^3 and the Arithmetic Mean (AM) was 0.190mg/m^3 and both the GM and the AM were above the old and new OEL of 0.050mg/m^3 and 0.025mg/m^3 respectively. Similarly, in the study by Kirkeskov, et al. [1], the silica dust concentration for demolition workers for the calculated 8-h-TWA was 0.08 mg/m^3 which was more than carpenters. Despite the concentration of 0.08mg/m^3 being lower than the OEL of 0.1mg/m^3, 45% of individual measurements for demolition workers calculated at 8-h-TWA exceeded the OEL of 0.1 mg/m^3 for silica dust in Denmark. However, Flanagan, et al. [15] found that abrasive blasters, surface and tuck-point grinders, jackhammers and rock drills had high silica dust exposures. Moreover, Flanagan, et al. [15] established that construction masons and labourers were frequently overexposed (0.11mg/m^3 compared to the limit of 0.05mg/m^3) to silica dust even though they prefer working without respirators as was observed. On the other hand, Rappaport, et al. [19] reported that painters experienced the highest exposure to silica dust of 1.28 mg/m^3 which was beyond the OEL of 0.05mg/m^3.

In Zambia, Hayumbu, et al. [18] conducted a study in the mining sector and found that the mean silica dust in the Nkana and Mufulira Copper Mines was 0.143 mg/m^3 and 0.060 mg/m^3 respectively. The silica dust in both Nkana and Mufulira Copper Mines were above the NIOSH REL of 0.050 mg/m^3 for respirable crystalline silica. The findings mean that more miners were exposed to high silica dust levels. In spite of Hayumbu, et al. [18]'s findings, there had not been any research in the construction industry in Zambia on silica dust exposure despite the fact that construction and mining have similar dust and silica dust generating activities such as breaking, drilling and quarrying. However, many people are not aware of dust as a potential hazard especially silica dust [10]. Therefore, it is paramount that silica dust levels are established and effectively reduced. To effectively reduce silica dust exposure levels, a combination of controls has to be employed [20]. This involves the use of methods in the hierarch of controls. There are five control methods in the hierarch of controls namely elimination, substitution [21], engineering control [4,15,22], administration control and the use of personal protective equipment [20]. The combination of controls will not only help in safeguarding worker's health but also reduce negative effects silica dust hazard has on the overall project such as loss of man-hours. The workers become ineffective on the project, thereby failing to meet construction schedules [20].

Materials and Methods

This was a cross-section study. Bricklayers, carpenters, batchers, tilers, demolition workers, painters and their handymen were purposively sampled and then randomly selected. The skilled and their handymen were purposively sampled after a thorough literature review on the most exposed in the construction industry. The silica dust samples were initially planned for 30 samples:15 from building and the other 15 from the road project. Despite planning for 30 samples, sampling was only conducted on the building project. This was because the road projects were discontinued because of the heavy rains. Therefore, the total number of silica dust samples was 15. The Methods of Determination of Hazardous Substances (MDHS101/2) through X-ray diffraction (XRD) for silica dust was used for sampling and analysis [23]. Personal sampling was collected at a flow rate of 2.2 L/min with a battery-operated Casella Apex2 sampling pump. The pump was attached to the employee's waist and connected through a tubing to a pre-weighted 25-mm, 5-µm pore size polyvinyl chloride (PVC) filter in a filter cassette. A 25-mm nylon cyclone was placed in the employee's breathing zone below the collarbone with the inlet pointing downwards. The data sampling was collected during work activity for 8hr- TWA.

The sampling for the silica dust was planned for three tilers, three bricklayers, three carpenters, three painters and three demolition workers. Nevertheless, during the data collection, labour had been reduced due to Covid-19 restrictions on site by the Ministry of Health as a preventive measure. Consequently, the researcher managed to collect data from four tilers, four bricklayers, five carpenters, two painters and one demolition worker as these were the available labour during the time of data collection. According to the literature review, the sampled professions were a representative sample for the construction skilled workers who were more exposed to silica dust. The 15 silica dust samples were sent for analysis to South Africa -National Institute for Occupational Health (NIOH) a division of National Health Laboratory Services (NHLS). The NIOH laboratory is a South African National Accreditation System (SANAS) Accredited laboratory with the accreditation number T0660. The Limit of Detection (LOD) for XRD was 0.005, Limit of Quantification (LOQ) was 0.018 and the uncertainty was 2.15%. The volume of sampled air was calculated using the flow rate of 2.2L/Min and the duration of sampling was 8 hours (480 min) and divided by 1000L in order to convert litres to cubic metres (m^3) as shown in equation One. The concentration was calculated in mg/m^3 as shown in equation Two.

Vs (m^3) = Flowrate (L/Min) x Time (Min)/1000L ……………………………………………………….. Equation One

Where;

Vs = Volume of sampled air (m^3)

Silica Concentration (mg/m^3) = Msilica (mg)/ Vs (m^3) ……………… ……………………..........................Equation Two

Where;

MSilica = final mass of silica done by XRD.

Vs = Volume of sampled air in m^3.

The AM and GM for concentrations were calculated for all the samples and for each job title or profession. One Sample Test was performed on the silica concentrations to test for significance using OSHA-PELs concentrations of 0.05mg/m^3. The data was analysed quantitatively using IBM Scientific Package for Social Sciences (SPSS) version 1.0.0.45 by means of descriptive and inferential statistics. Pearson Chi-square and degree of freedom were used to test the degree of association between the independent and dependent variables. The level of significance of $\rho < 0.05$ and confidence interval of 95% were considered as statistically significant. For the results to be statistically significant under One-Sample Test: Using the Degree of Freedom (df) and the two-tailed in the student's t Distribution Table, the found Critical Value (CV) should be less than the t in the One-Sample Test, the ρ value should be less than 0.05. The 95% confidence interval should not cross the zero.

Results and Discussion

Silica dust sampling was conducted in January 2022 and analysis was done in March 2022. Using the flow rate of 2.2L/Min and the

8h-TWA (480min), volume of sampled air was calculated as 1,056L. The volume of sampled air was then used to calculate the concentrations. The results for concentrations are presented in (Table 1) . The highest individual concentration for silica dust was 1.582mg/ m^3 which was 96% higher than OSHA PEL. The overall GM for all the job titles for Respirable Crystalline Silica (RCS) dust was 0.04mg/ m^3 which was 20% less than OSHA PEL of 0.05mg/m^3. The overall AM for all the job titles for RCS was 0.228mg/m^3 which was 0.178 (78%) more than OSHA PEL of 0.05mg/m^3. On the individual exposures in the current study, 40% were above the OSHA PEL while in Normahammadi, et al. [2]'s study 80% of the workers were exposed to levels more than OELs. The difference in the findings could have been that Normahammadi, et al. [2] sampled the demolition workers only whereas in this study, sampled workers were bricklayers, carpenters, painters, demolition workers, tilers and their labourers. The carpenters and their labourers had the highest GM (0.1582mg/m^3) for RCS compared to bricklayers (0.007mg/m^3), demolition workers (0.029mg/m^3), tilers (0.010mg/m^3) and painters (0.026mg/m^3). This is unlike the finding by Lumen and Spee, [10], Normahammadi, et al. [2] and Kirkeskov, et al. [1] who suggested that demolition workers are more exposed to silica dust.

Table 1: Exposure Levels for Respirable Crystalline Silica (RCS) Dust.

Job Title	RCS (mg/m^3)	Silica Content (%)	RCS (GM) (mg/m^3)	RCS (AM) (mg/m^3)
Tiler Handyman	0.02	3.32	0.01	0.055
Tiler	0.062	18.01		
Tiler	0.082	2.91		
Bricklayer Handyman	0.016	6.64	0.007	0.008
Bricklayer Handyman	0.004	2.24		
Bricklayer	0.007	11.25		
Bricklayer	0.007	8.54		
Carpenter Handyman	1.048	15.1	0.195	0.627
Carpenter	0.446	3.64		
Carpenter	0.051	8.95		
Carpenter	0.008	8.54		
Carpenter	1.582	4.28		
Painter	0.016	2.31	0.026	0.03
Painter	0.044	8.95		
Demolition Worker	0.029	1.46	0.029	0.029
Overall		6.8	0.04	0.228

Moreover, the finding is different from Rappaport, et al. [19] who reported painters to be more exposed and Flanagan, et al. [15] who found that masons and their labourers were more exposed to silica dust. In the case of Rappaport, et al. [19], painters performed abrasive blasting that is why they had higher exposures. The reason for the difference in the current results would have been that carpenters were drilling and cutting concrete blocks indoors while the sampled demolition worker was working outdoors. The GM for RCS (0.04mg/ m^3) was comparable to Li, et al. [4]'s findings of 0.03mg/m^3. This was despite Li, et al. [4] having 723 personal air samples while this research had 15 samples. Nevertheless, the GM found in this study was less than 0.11mg/m^3 which was found in the study by Flanagan, et al. [15]. The difference in the two studies may have been that full shift was used in this study while Flanagan, et al. [15] used half shift. Moreover, this study focused on specialised workers or job title or profession while in the study by Flanagan, et al. [15], the focus was on the activity. Also, the GM findings of the present research was different from Lumens and Spee [10] whose GM was 1.1mg/m3. The AM exposure level (0.228mg/m^3) was 78% more than OSHA PEL of 0.05mg/ m^3. The AM concentration (0.228mg/m^3) for this research was more than 0.190 mg/m^3 by Normahammadi, et al. [2]. This is regardless of the GM level of 0.04mg/m^3 in this study being lower than the GM of 0.132 mg/m^3 by Normahammadi, et al. [2].

The mean RCS exposure level was 0.119mg/m^3 which was 58% above and 2.4 times the OSHA PEL. The highest exposure was 97% above and 32 times OSHA PEL. The silica content in this research ranged from 1.5 to 18% which were lower than Lumen and Spee [10] who found over 40% and Flanagan, et al. [5]'s study whose range was from 2.2 to 21%. However, it is higher than 15% which was found by Li, et al. [4]. The silica content in the current research gives an indication of high silica dust exposures. The exposure levels were recorded into high and low (above OSHAL PEL as high and below OSHA PEL

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as low) and analysed using SPSS. The cross-tabulations between exposure levels and the job title showed that there was no relationship as the ρ >0.05 for RCS (0.105) as shown in (Table 2). Despite all the skilled recording different silica exposure levels and carpenters recording highest exposure level, there was no statistical significance between job title and RCS. This means that the exposure levels do not depend on the job title. However, the findings of different exposure levels in the job titles during air sampling would mean that the exposure levels depend on the activity being carried out as suggested by Flanagan, et al. [15]. This can be seen in the results of carpenters recording highest exposure levels compared to other job titles. This was because carpenters were drilling and cutting concrete indoors, for their activities on the building project as suggested by Li, et al. [4] that such activities produce high silica exposure levels.

Table 2: Job Titles in relation to Respirable Crystalline Silica Dust Exposure Levels.

Job Title	Frequency (%)	Silica Dust Exposure Levels		ρ-value
		Low N (%)	High N (%)	
Tiler Handyman	6.7	1(100)	0(0)	0.105
Tilers	13.3	0(0)	2(100)	
Bricklayer Handymen	13.3	2(100)	0(0)	
Bricklayers	13.3	2(100)	0(0)	
Carpenter Handyman	6.7	0(0)	1(100)	
Carpenters	26.7	1(25)	3(75)	
Painters	13.3	2(100)	0(0)	
Demolition Worker	6.7	1(100)	0(0)	

The important thing is that the findings showed that the sampled skilled were exposed to high silica levels which were above OSHA PEL and these skilled may perform similar activities that produce high silica dust. One-Sample Test was also conducted to find if it was statistically significant that the silica dust levels were above the OSHA PELS of 0.05mg/m^3. The results showed that RCS exposure levels were above the OSHA PEL of 0.05mg/m^3 as shown in (Table 3) . Using the df =14, at 95% confidence (0.05) and two-tailed, Critical Value (CV) was found as 2.145 in the student's t distribution table. The t > CV, ρ <0.05 and at 95% confidence interval of the difference; lower = 1.069, upper = 1.63, did not cross the zero. Therefore, the result was statistically significant. This means that the silica dust levels construction specialised personnel were exposed to were above OSHA PEL. Levels above OSHA PEL are considered high exposures that can lead to respirable diseases. This finding of high silica dust levels above 0.05mg/m^3 were like discoveries by Normahammadi, et al. [2] and Flanagan, et al. [15].

Table 3: One-Sample Test for RCS Dust Using OSHA-PEL of 0.05mg/m^3.

	Test Value = 0.05					
	t	df	Sig. (2-tailed)	Mean Difference	95% Confidence Interval of the Difference	
					Lower	Upper
RCS	10.311	14	0	1.35	1.069	1.631

Conclusion and Recommendations

The research findings revealed that the construction specialised personnel were exposed to silica dust levels above OSHA PEL of 0.05mg/m^3. This means that the bricklayers, carpenters, batchers, tilers, demolition workers, painters, and handymen in the construction industry in Zambia were exposed to silica dust levels that were harmful to their health. Inhaling silica dust above the concentration of 0.05mg/m^3 can lead to respiratory diseases such as chronic obstructive pulmonary disease, renal disease, tuberculosis, lung cancer and silicosis. On the profession or skill level, the research established that despite carpenters and their handymen recording highest silica dust exposures, it was not statistically significant. All the sampled skilled experienced high silica dust exposure levels. It is recommended that effective silica dust controls should be well utilised on sites. The recommended preventive measure is the combination of all controls according to the hierarchy of controls namely, elimination, substitution, engineering control, administrative controls and skilled suitable and quality PPE. Moreover, the use of engineering control such as LEV which controls dust from the source and water which suppresses dust thereby reducing exposure levels, are recommended. The use of LEV and water has proved to reduce silica dust exposures levels meaningfully. Also, it is recommended that a preventive framework for silica dust exposures is developed. This is because Zambia has not yet established silica dust exposure limit and does not have a laboratory to sample and analyse silica dust for the purposes of monitoring. The preventive framework and establishing a laboratory would help safeguard the health of the workers who are the most important resource in construction and would also promote high productivity.

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