

Effectiveness of controls for respirable crystalline silica dust exposure in construction: A literature review

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Abstract:

Silica dust is unavoidable hazard, which is produced from construction activities such as grinding, cutting concrete and other materials that contain silica. Respirable silica dust can lead to occupational diseases such as chronic obstructive pulmonary disease, renal disease, tuberculosis, lung cancer and silicosis. In construction, workers are exposed to levels of respirable silica dust that are beyond the Permissible Exposure Limit which makes them prone to deadly respirable diseases. This paper reviews the effectiveness of exposure controls that are used in construction to reduce exposure levels to permissible limits. Eight studies that measured the reduction of exposure levels of controls were reviewed. Other sources of information were reports, reviews of Health, Safety and Environment (HSE) and National Institute for Occupational Safety and Health. The paper is only based on the review of literature and case studies in construction. Peer reviewed articles and other articles on respirable crystalline silica exposure controls in the construction industry were reviewed. Water control was found to be more effective compared to local exhaust ventilation and the use of a silica substitute materials. Nevertheless, the use of water alone could not reduce exposure levels below the permissible limits. The implications of the study clearly demonstrated that there is no one single control was able to reduce exposure levels to permissible levels. In one study the combination of two controls, water and local exhaust ventilation reduced exposure levels significantly below the permissible level. Reduction in exposure levels will help in safeguarding workers' health for high productivity. The use of all the controls in combination is recommended for the effective reduction of silica dust exposure below the permissible levels.

Keywords:

Controls, construction, exposure, effectiveness, silica dust

1 Introduction

The importance the construction industry plays in the world economies cannot be over emphasized. Nevertheless, construction is one of most dangerous industry in terms of hazards and risks that cause accidents and occupational diseases (Tente, 2014). One of the health hazards is respirable crystalline silica (RCS) which is contained in several construction materials such as concrete and sand. In construction, exposure to dust is part of activities from excavation of foundation to cleaning up site after completion (Lumens and Spee, 2001; Dixon, et al., 2020). In highway maintenance, road construction and repair workers are potentially exposed during sawing, breaking and

grinding concrete and other materials that contain silica (Valiante *et al*, 2004). In addition, activities such as mortar removal, sanding, grinding and cutting do produce respirable crystalline silica. According to the Health and Safety Executive in the United Kingdom (HSE, 2012), respirable crystalline silica can lead to occupational diseases such as chronic obstructive pulmonary disease, renal disease, tuberculosis, lung cancer and silicosis; (Valiante *et al*, 2004). Silicosis takes long to develop and its symptoms are; shortness of breath, wheezing, chest tightness and coughing (Valiante *et al*, 2004).

There are some factors that contribute to high silica exposure levels in construction. Some of the factors are; dusty working methods, less use of Local Exhaust Ventilation (LEV), no natural ventilation for some works, improper use of Respiratory Protective Equipment (RPE) and the use of high silica content materials (Lumens and Spee, 2001). The higher the silica content in construction materials the higher the exposure levels. Therefore, there is need for possible reduction of silica content in construction materials as one of the ways to reduce exposure levels (Thorpe *et al* 1999). Lumens and Spee, (2001) indicated that dust exposure on construction site is unavoidable and many people are not aware of it as a potential hazard. Moreover, dynamics of construction poses a challenge in development and application of controls for respirable dust and respirable crystalline silica dust (Lumens and Spee, 2001). Nevertheless, there are a number of controls that are used in construction to reduce exposure levels of respirable dust and respirable crystalline silica dust. The results from several studies show that without any exposure controls, some construction activities produce excess respirable dust (HSE, 2012). Respirable crystalline silica dust is preventable (Carlo *et al*, 2010). Therefore, there is need to implement effective control measures to reduce exposure levels of respirable crystalline silica dust in construction to Permissible Exposure Limit (PEL). This paper reviews the effectiveness of respirable crystalline silica controls in the construction industry.

2 Literature Review

The construction industry in Zambia is not unexceptional to silica dust and chemical irritants hazards. As Zambia aspires to be a prosperous middle-income country by 2030, there are planned strategies in the 7 National Development Plan 2017-2021 in the construction industry. Under the Economic Diversification and Job Creation, Outcome number six, government planned to prioritise construction and rehabilitation of railways, aviation infrastructure, road network and marine and inland waterways. This entails increase in construction projects and job creation in the industry. There is a likelihood of an increase in the generation of dust and possible contact to silica dust and chemical irritants. Construction companies, however, are hesitant to adhere to Occupational Safety and Health Laws (Tente, 2016). This means that more personnel are being employed and more materials and chemicals are used during the execution of the projects. The exposure to silica dust and chemicals may be increased as activities such as jack hammering, rock drilling, concrete mixing, sanding, brick and concrete block cutting and sawing, clearing and grading, tile cutting and demolition are part and parcel of construction. Construction personnel who are specialised in such activities like bricklayers, batchers, tilers, carpenters, painters, road construction and demolition workers may be more exposed to silica dust and chemicals. Moreover, despite the increasing mechanisation in construction and frequent use of precast concrete sections, contact with wet cement still occurs, especially in small jobs. Therefore, there was need

for a study as this one to find ways of reducing the exposure to silica dust and chemical irritants to safeguard the construction workers and also to reduce the effects of silica dust and chemical irritants on the overall construction projects.

2.1 Controls of respirable crystalline silica dust in construction

The controls of respirable crystalline silica dust fall within the hierarchy of controls. The hierarchy of controls has five controls namely, elimination, substitution, engineering control, administration control and the use of personal protective equipment:

- a) **Elimination method:** Elimination method involves the physical removal of a hazard and is the most effective control. However, elimination method is almost not practical in construction especially with the use of crystalline silica materials that are extensively used like cement and sand (Thorpe *et al* 1999).
- b) **Substitution method:** Substitution method is replacing the more hazardous materials or activities with lesser hazardous ones (Radnoff and Kutz, 2013). For example, in the study by Kirkeskov *et al.*, (2016), manual demolition was substituted with mechanical demolition. This is because manual demolition had higher silica dust exposure levels than mechanical demolition (Kirkeskov *et al.*, 2016). However, in some cases substitution does not make much difference like in the case of Radnoff and Kutz, (2013), the use of silica substitute did not have a large effect on the exposure levels.
- c) **Engineering control:** Engineering control is the way of removing the hazard at the source before it comes to contact with the worker. There are several engineering respirable crystalline silica dust control methods that are used in the construction industry. Some of the engineering control employ the use of area fans, ducted fan exhaust, sweeping compound (dyed saw dust, sand and oil) and water application to cutting materials (Flanagan *et al.*, 2003). The general ventilation (GV), local exhaust ventilation (LEV) and wet dust suppression are also used to control respirable crystalline silica exposure (Thorpe *et al* 1999; Lumens and Spee, 2001).

Local exhaust ventilation involves the capture of air contaminants at a source. A local exhaust ventilation system consists of a hood or enclosure to capture a contaminant, an air pollution control device to clean the air, and an air mover to provide air flow through the system (Raynor and Peters, 2016). These systems range from small portable units, such as a High-Efficiency Particulate Arrestance (HEPA)-vacuum system (Figure 1a), to extensive, permanent installations typical of large industrial facilities (Figure 1b) (*ibid*). The air containing dust is then filtered before it is released to the air (Hasan *et al.*, 2012).

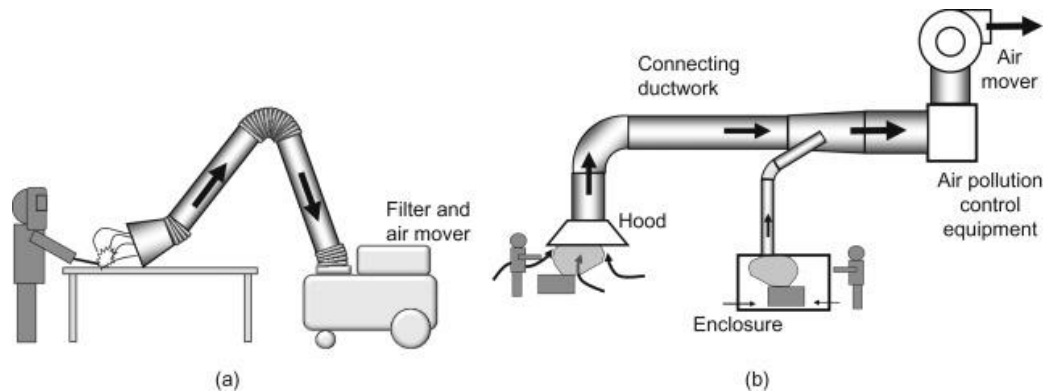


Figure 1: High-efficiency particulate arrestance (HEPA)-vacuum system (a) and Permanent installations typical of large industrial facilities (b) (Source Raynor and Peters, 2016)

The wet dust suppression is done by applying water to the rotating cutting disc of the powered hand tools to reduce dust emission (Thorpe *et al.*, 1999). Flanagan *et al* (2006), established that engineering controls reduced silica dust exposure. The engineering controls, unfortunately, were infrequent and so did not control exposure below the PEL of 5.0 mg/m³ which was used for their study. What was not established in their research was how effective each control was in terms of silica dust controls.

- d) **Administrative controls:** Administrative controls deal with the change of behaviour of workers in terms of training and awareness on how to lessen the risk of a hazard on an individual (National Institute for Occupational Safety and Health -NIOSH, 2009; Mwanaumo *et al*., 2014). For example, offering training in the proper use of tools fitted with controls for crystalline silica exposure to the workers has been recommended (HSE, 2012). Another example is to rotate workers for an activity to keep exposure under PEL. Administrative controls are mostly recommended when elimination, substitution and engineering controls have failed to completely control the hazard (NIOSH, 2009).
- e) **Personal protective equipment (PPE):** Since the use of engineering controls such as wet dust suppress and LEV do not completely eliminate respirable crystalline silica dust below Permissible Exposure Limit (PEL), Respiratory Protective Equipment (RPE) is required (HSE, 2012). According to 1987 study by Reed *et al.*, the most common control measure for silica dust, in construction industry was Personal Protective Equipment (PPE). Respiratory protection is usually inadequate for the exposure that are encountered in construction (Flanagan *et al*, 2003). When respirators do not fit well, protection is compromised. Therefore, proper selection of the RPE should be done and they have to be stored properly (Radnoff and Kutz, 2013). Kirkeskov *et al*, 2016 found that only few workers used personal respiratory protection and only while performing the dustiest work. This is the more reason why engineering controls should be encouraged. Moreover, respirators only protect the user not the nearby workers. Despite quality and efficient respirators being more expensive and require maintenance, they have to be provided to effectively control dust exposure levels of workers (Flanagan *et al*, 2003).

This research is focused on silica dust and chemical irritants because they are related in terms of construction materials that produce the hazards. Silica content materials in their wet state produce chemicals that are irritable to the skin and in their dry state produce silica dust during grinding, cutting, sanding and other construction activities. One such example of construction material is concrete. In its wet state, it poses chemical irritant hazards and in its dry state, produces silica dust when it is being worked on through activities like cutting and grinding. Several studies have revealed that the levels and period of exposure to chemical irritants are important to the development of skin diseases. According to Mashqoor et al. (2017), 78% of the workers did not have any Personal Protective Equipment (PPE). Similarly, in the study by Bedoya-Marrugo et al. (2017), 70% of respondents did not use PPE. Moreover, Shah and Tiwari (2010) found that 50% of the workers did not use PPE. This meant that the workers without PPE experienced high exposure levels to chemical irritants and were likely to develop symptoms of skin diseases. This would have been the reason for high rate of skin diseases in the construction industry. Period of exposure to chemical irritants have also been associated to occurrence of symptoms of skin diseases. Shah and Tiwari (2010) found that there was an association between increased duration (8-10 hours) of exposure and skin conditions. The skin symptoms were work related and were aggravated by work. In the study by Bedoya-Marrugo et al, (2017), it was found that the period of exposure to cement was directly proportional to likelihood of developing dermatitis. Prolonged duration of exposure was associated with more morbid skin conditions (Moshqoor et al., 2017).

3 Methodology

The literature review was conducted between May 2021 and November 2021. Peer reviewed articles in peer-reviewed journals, conferences, books, book chapters and other articles on respirable crystalline silica exposure controls in the construction industry were reviewed. The articles reviewed were both from developed and developing countries. The peer-reviewed articles that were reviewed were between 1995 and 2021. Other sources of information were reports, reviews of HSE and NIOSH. Eight studies were selected for use in this paper and had different controls which focused on the reduction of respirable crystalline silica in construction. The articles reviewed had different work shifts; full shift of 8h Time Weighted Average (TWA), half shift and in some cases less than half shift. This is because most of the construction activities that were sampled were not performed by one person continuously.

4 Results and Discussion

This research is focused on silica dust and chemical irritants because they are related in terms of construction materials that produce the hazards. Silica content materials in their wet state produce chemicals that are irritable to the skin and in their dry state produce silica dust during grinding, cutting, sanding and other construction activities. The most common dust control used on sites was a combination of water and dust masks (52%) followed by dust masks only (24%). The control by use of water only was 10% and no control was five percent. Most of the studies that have been done concerning respirable crystalline silica exposure controls have been on the on-tools controls such as grinders, cut-off saws, hand-held saws. Silica dust exposure levels differ from profession to profession and task to task despite working on the same construction sites (Kirkeskov *et al*, 2016; Mwanaumo, et al., 2018; Mambwe, et al., 2021). Flanagan *et al*, (2003)

established that abrasive blasters, surface and tuckpoint grinders, jackhammers and rock drills experience high levels of silica dust exposure. These kinds of professions usually use handheld powered tools for their work which involves grinding or cutting of construction materials that contain silica. This could be the reason for many studies are on the on-tools controls. Moreover, from the reviewed articles, it can be noted that in construction, the most practical control in the hierarchy of controls is engineering control. Administrative and RPE are used to where hazards are not particularly well controlled by engineering control and are usually last in line. In addition, the reviewed studies used different PEL.

Several countries have recorded high silica exposures that pose a high risk of respiratory diseases to construction workers. Therefore, there is a concern for the high silica dust exposure levels in construction. In Switzerland, 80% of the measurements of exposure levels for demolition and reconstruction were above 0.15mg/m³ which was the PEL (Moser, 1992). According to Riala (1988), Finland recorded silica exposure levels of 0.53mg/m³ during dry season. Similarly, Lumens and Spee, (2001), suggested that silica exposure levels were above 0.075 mg/m³ in Netherland's construction industry.

The compilation of the results from the eight studies by different researchers are presented in Table 1. It can be seen from the results that no one single control was able to reduce exposure below PEL. The results show that water control which has a reduction of above 90%, is more effective compared to LEV and the use of silica substitute materials. However, there are few concerns with water in terms of slip hazards and decolouring during roofing when cutting tiles with the saw (Carlo *et al*, 2010). The effectiveness of water to reduce silica dust exposure on the on-tools depend on the water volume, flowrate and the blade size. Nevertheless, in some studies which have been done on the controls of respirable crystalline silica exposure, there was no statistical significance effect in control efficiency for factors such as water volume, flow rate and blade size (HSE, 2012).

Table 1: Silica exposure reduction by some authors

Item	Control Type	No Control (mg/m ³)	Control (mg/m ³)	Reduction %	PEL (mg/m ³)	Source
1	Pressure Tank	21.2	1.3	95	0.04	Thorpe, <i>et al.</i> (1999)
	Mains Water	14.4	0.6	93		
	LEV	8	0.7	91		
2	LEV	1.0	0.3	70	0.075	Lumens and Spee (2001)
3	LEV on-tool and Box Fan	4.87	1.42	71	0.075	z
4	LEV and Water	14.3	Below PEL	99	0.075	Nij, <i>et al.</i> (2003)
5	LEV	4.5	0.14	92	0.075	Croteau <i>et al.</i> (2004)
6	LEV on-tool	25.4	0.95	99	0.025	Akbar-khanzadeh, <i>et al.</i> (2007)
	Wet grinding	61.7	0.11	98		
7	LEV	1.4	0.13	91	0.075	Carlo, <i>et al.</i> (2010)
	Water suppression	3	0.03	99	0.075	
8	Silica substitute	0.074	0.049	66	0.025	Radnoff and Kutz (2013)

LEV (Local Exhaust Ventilation), **PEL** (Permissible Exposure Limit)

The other control which reduced exposure 99% is LEV on-tool. The advantage of LEV is that it reduces exposure to nearby workers and minimises the clean-up due to dust exposure. The problem with LEV on-tool is that it adds more weight to the equipment or tool. The use of silica substitute materials reduced 60% of exposure. This entails that the use of silica substitute materials should be incorporated in construction to help reduce exposure levels. The combination of LEV and water showed significant reduction which was below the PEL of 0.075mg/m³. This clearly shows that the combination of all controls which are LEV, water, the use of silica substitute materials, training and the proper use of quality RPE would reduce exposure to safeguard the workers' health which is paramount.

The use of RPE is the mostly used control on many construction sites especially in developing countries. However, the more recent studies have shown that there have been improvements to the use of engineering controls. Several studies have shown that construction activities produce high levels of silica dust. In addition, Table 1 shows that of the eight reviewed articles, only one had the reduction level which was below PEL. It could be concluded that the use of RPE as a control, is far from reducing exposure levels to below PEL. More research is recommended especially in developing countries to assess silica exposure levels in construction and find preventive measures that will help reduce the high levels of silica dust exposure.

5 Conclusion

The most effective control of silica dust exposure in construction is the combination of all controls. Water, LEV, the use of silica substitute materials, training or awareness and the proper use of quality RPE reduces exposure levels below the PEL. The use of combination of all controls may seem expensive in the short term but it is cheaper in the long term. The main focus should be on reducing the risk of ill health for the construction workers rather than the cost as suggested by Thorpe *et al.* (1999). Prevention is not only better but also cheaper in the long term. It is therefore important to reduce exposure levels to PEL to safeguard the workers' health which is not only paramount but also is a legal obligation for many countries.

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