

Occupational Exposure to Dust in Open Pit Mining. A Short Review.

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ABSTRACT

A literature review concerning the scientific knowledge of all the key factors related to respirable crystalline silica dust exposure was conducted and a chronological evolution of the state-of-the-art knowledge that can respond to questions raised by the development of the work done in quarries and opencast mines is presented, based on bibliographic research. Findings assert that exposure to silica dust is the most frequent and dangerous hazard in open pit mining. Some aspects meet consensus amid authors: tasks and work equipment, areas surrounding the quarry, methods of sampling, relationship between the amount collected and the legal limits set (TLV) in each country. "Good practice" preventive strategies towards the protection of the exposed workers comprehend early knowledgeable recognition of the danger followed by application of technical means of exposure control. A review evidence concerns the link between exposure, by inhalation of dust containing crystalline silica, and its harmful effect to human health, often deadly (silicosis). Authors noted that other work-related factors associated to exposure to silica dust may potentiate other occupational diseases. Silicosis is a preventable occupational disease, but not curable, accounting for new cases of death even among young workers. Thus an effective mandatory control of exposure to crystalline silica in the workplace is therefore crucial.

Keywords: Silica dust; open-pit mining; occupational prevention.

1. INTRODUCTION

Occupational exposure to dust is one of, if not the main health risk originating from quarries and mines. It's closely associated with almost all the phases of the production process. From the general concept of risk, defined as the probability of an event being held in conjunction with the consequences of exposure to a substance, arise a number of other factors that must be analyzed in detail. Thus, in addition to the hazardous substance - respirable crystalline silica dust, the target must be considered - the exposed worker, an entry point into the human body, the place of exposure - work place (post or work equipment), time or duration of exposure, as well as the frequency of exposure, so that the hazardous substance may or may not exercise its adverse effects. Dust is generated at all stages of production and the smallest dust particles, therefore invisible in size, are the most dangerous due to their ability to reach the lower part of lung (the alveolus) (Orme, 1998).

2. OBJECTIVES

In order to consolidate the knowledge of all the key factors related to respirable crystalline silica dust exposure a bibliographic research was conducted. The general purpose was to present the state of the art for each of the crucial factors and the relationships established. This paper aims to present a chronological evolution of scientific knowledge that can respond to questions raised by the development of the work done in quarries and opencast mines. The research main objective involved the dust hazardous substance(s) and their effect on the target under analysis: i) the exposed worker, knowledge of the route of entry into the body of the exposed worker; ii) the airways, the site of exposure; iii) different equipment and work places, time or duration of exposure and the frequency of exposure.

3. METHODOLOGY

The present review is based on bibliographic research, Metasearch variant, using the search engines available at the Faculty of Engineering, of the University of Porto, which is conducted in Databases and Scientific Journals. The research was initially done for all the Databases and Scientific Magazines available and gradually restricted to the resources effectively relevant and articles of interest. Thus, the resources that have been proved to be more productive, from the Database, were the following: Compendex, Current Contents, Web of Science and from the Scientific Journals, the ACS Journals, Highwire Press and Wiley Online Library. PubMed was another database searched and proved of great interest in connection to the subject matters of Occupational Health. The research has been developed by combining a set of keywords that were predefined; the search was made in all available fields, excepting when the number of results of each research was too long for analysis, and then it was restricted to one field only. The logical operator between keywords used was "And." The research fields that returned better results with interest were "Subject" and "All fields", being the most comprehensive, when used alternately and respectively as 1st and 2nd keywords. During this process and when the number of articles was in very large numbers, about 1899 articles, refining the search, combining it with another expression, limiting the results to the logical "and" a 3rd keyword or, alternatively, refining the search of the years between the publishing options "dates (2000-2005)", "dates prior to 2000" and "Dates after 2005" or by searching for "Year" to year. The logical operator between keywords used was the option to "And." The fields of research that showed better results were - "Subject" and "All fields". They have interest, because they are the most comprehensive, when used interchangeably and respectively in the 1st and 2nd keywords.

From the results, 45 articles were selected that appeared relevant to the topic and are presented by valid evidence of its scientific rigor and whose data / observations to show sustained or properly validated. Subsequently, the screening process of scientific articles arising from various searches was made and in most of the situations, based on the summary information provided. And in some situations when an article reveals more importance, through access to the full article, more detailed and complete information can be obtained. The group formed between the permanent term "Occupational Dusts" as the first keyword and as 2nd keyword "Extractive Industry", were assessed in all fields of research available. In order to refine the search, different keywords were introduced: "*Opencast mining industry*", "*Open pit mining industry*", "*Quarry*", "*Equipment quarry rock*", "*Drilling equipment*" and "*Transportation equipment in extractive industry*". In order to continue to restrict the search in any one of these searches was also used another strategy, which allowed the search of articles published within the ranges of "dates". Thus, after refining and suitable for evaluation set out above, a database was constructed, with the articles grouped in areas of interest based on the study objectives.

4. RELEVANCE OF RESULTS

4.1. Characteristics of potentially dangerous substance - respirable crystalline silica dust

Considering the research main target, occupational dust, all articles have a common data, revealing that exposure to silica dust is the most frequent and dangerous hazard in open pit mining. Because of the references made throughout the review, formulated in a more or less general way to silica dust, it should be noted as referring to crystalline silica dust in the respirable particle size, which is present in its basic form quartz α , being the most abundant toxic silica.

The component most widely recognized as dangerous, are the particles of crystalline silica that in excessive exposure can cause serious respiratory problems or silicosis (Orme, 1998) and considered as class 1 - carcinogen, confirmed in a study by Peretz & Checkoway (2006) and in an earlier studied by the working group led by Donaldson (Donaldson & Borm, 1998). However, this author noted that the carcinogenicity to humans was not detected in all industrial circumstances, verifying that this may depend this may depend on inherent characteristics on inherent characteristics of the crystalline silica or external factors affecting its biological activity.

Demircil and Scarselli in their studies (Demircigil, 2010), (Scarselli & Binazzi, 2011), in Turkey and Italy respectively, concluded that the activities of rock blasting, crushing and grinding, are classified at high risk of exposure, especially in developing countries, where awareness to this problem is smaller. Mikolajczyk, in its study in coal open pit mines in Poland (Mikolajczyk, 2010), concludes that exposure to silica dust remains the biggest problem in industrial hygiene and occupational medicine in that country. When dealing with crystalline silica, the focus is particularly on quartz, because it is the most abundant mineral on the surface, with an approximate value of 20 percent in the earth's crust (Madsen et al., 1995).

4.2. Place of Exposure - jobs and work equipment. Definition of TLV - Threshold Limit Values.

Another field of research, object of consensus amid several authors is the place of exposure - tasks and work equipment, areas surrounding the quarry, methods of sampling, relationship between the amount collected and the legal limits set in each country.

For example, Golbabaie (2004), conducted a research in a stone quarry of marble located in the northeast of Iran. Time weighted average of total dust, respirable dust, and crystalline silica (α -quartz) concentration in the workers' breathing zone were monitored by using both gravimetric and XRD methods. The results showed that the employees working in hammer drill process had the highest exposure to the total and respirable dust: $107.9 \pm 8.0 \text{ mg/m}^3$, $11.2 \pm 0.77 \text{ mg/m}^3$ respectively, while the cutting machine workers had the lowest exposure ($9.3 \pm 3.0 \text{ mg/m}^3$, $1.8 \pm 0.82 \text{ mg/m}^3$). The maximum concentration of α -quartz in total and respirable dust were detected equal to $0.670 \pm 8.49 \times 10^{-2}$ and $5.7 \times 10^{-2} \pm 1.6 \times 10^{-2} \text{ mg/m}^3$ respectively, which belonged to the exposure of the workers of hammer drill process. The prevalence of skin and respiratory symptoms were higher in hammer drill workers, however, respiratory symptoms showed no significant prevalence. Regarding the average age of workers ($31.6 \pm 1.9 \text{ yr}$) and average of their work history ($3.8 \pm 1.0 \text{ yr}$), these results were predictable.

Bahrami also reports the sampling methodologies and analytical studies of quartz quarries and find values of exposure exceeding the TLV (Threshold Limit Values), (Bahrami, Golbabaie, Mahjub, Qorban, Aliabadi, & Barq, 2008).

One of the mandatory requirements specified in laws or standards of most countries including the United States of America and Europe and inherently Portugal, in the area of occupational health and safety, is the evaluation of occupational exposure of workers to chemicals in the workplace.

The assessment of occupational exposure of workers to these agents consists in determining the concentration of these agents in the air of workplaces through methodologies and equipment specified in standards and their subsequent comparison with reference values, which represent acceptable levels of exposure.

These values are studied and proposed by U.S. government agencies such as NIOSH-National Institute for Occupational Safety and Health (NIOSH) and the ACGIH-American Conference of Governmental Industrial Hygienists and introduced into European standardization through ISO standards, which are incorporated in the standardization system of each member country.

Scarselli, in his paper "Occupational exposure to crystalline silica: estimating the number of Workers Potentially at high risk in Italy" (Scarselli, Binazzi, Marinaccio & 2008), estimate the need of approximately 10 to 15 years of occupational

exposure are required to cause silicosis, and a 5–10% likelihood to develop the disease is estimated in workers exposed during 20 years to silica concentrations of about 0.1 mg/m^3 .

This level is the TLV (Threshold Limit Values) allowed for 8 hours of exposure defined by OSHA for respirable crystalline silica in the United States. Recently, the ACGIH reduced the TLV allowed for eight hours of work exposure to 0.025 mg/m^3 . Following the most recent values defined by the ACGIH, in Portugal, it is recommended that for reference values are used TLV defined in the Portuguese Standard 1796:2007 (NP1796, 2007). Measuring the concentration of chemical agents and compare with the exposure limit values (TLV's) is a set of ways to undertake the evaluation (Matos, Santos, & Barbosa, 2010). This standard specifies the TLV and defines them as the concentration of chemicals to which it is considered that nearly all workers may be exposed, day after day without adverse health effects. These TLV are designed to use in practice of the Health and Safety at Work and are only guidelines or recommendations for control of potential health risks in the workplace, taking into account that the levels of contamination should always be the lowest possible. The parameter typically used as a comparison with the values obtained from collections made is the exposure limit value weighted average (TWA), which is by definition a weighted average concentration for a day's work of 8 hours and 40 hours a week.

The value stipulated in the Standard referred to crystalline silica is $\text{TLV-TWA} = 0.025 \text{ mg/m}^{3(R)}$ where (R) is the Respirable fraction, with a notation A2, which considers crystalline silica as a suspect carcinogen in humans. This notation is used especially in cases where there is limited evidence of carcinogenicity in humans and sufficient evidence of carcinogenicity in experimental animals with relevance to humans.

In a study conducted by Vinzents, collected samples of total dust and respirable dust (Vinzents, 1995), in view of the results can be used as tentative of establishing occupational exposure limits, concluding that these concentrations vary by type of industry and the results depend on the industry type and the content of the dust. There are also authors expressing some concern, not only by the exposure of workers in their jobs, but also related to people living in the surrounding areas of this type of industries.

In this sense, the work presented by Mukhopadhyay (Mukhopadhyay & Ramalingam, 2011), refers to a sampling, analysis and evaluation of particles in the workplace, $\text{PM}_{2.5}$, PM_4 and environmental dust / total – PM_{10} , conducted over 2 years, in order to test a system for control of dust in suspension by wet process.

4.3. Preventive measures.

In order to try reducing concentrations to below the TLV, in addition to early recognition of the danger and use of technical means of control, some measures should be taken. The knowledge of the situation of exposure to this type of dust, i.e., recognition of danger, is the first step towards the protection of exposed workers. The application of technical means of control can be considered as a "good practice" measure by the sole fact that prevents exposure. A large part of the work developed in the industry generates dust and consequently over-exposure of workers to respirable crystalline silica dust, which contributes significantly to mortality and occupational morbidity. Meeker (2009) evaluated the performance of portable personal control systems that were commercially available. With these systems, reductions of up to 96% in the concentration of respirable quartz exposure between workers with and without control have been achieved. However it can be concluded that there is a need to establish strategies to improve the performance of this type of equipment (Meeker, Cooper, Lefkowitz, & Susi, 2009). Other preventive measures, such as, regular medical examinations, respiratory protection and training, should be taken. The training given to workers at the beginning of their professional activity is important, but recycling programs are also important. Personal Protective Equipment (PPE) should be used as a last resort given the fact that its use is usually sporadic, unless, the supervising authorities intervene with a tight periodicity. Respiratory masks do not reveal effective protection for very high dust concentrations (Thomas, 2010).

Most operations of extraction and processing of rocks result in the release of significant amounts of dust. These dusts are released not only to the workplace but also for the atmosphere of the surrounding areas of the quarries. We have always been used dust suppression systems and direct exhaust systems from dust, so they were totally or at least partially removed from the workplace.

The need for maximizing the effectiveness of available dust suppression systems in conjunction with other effective controls, such as water sprays and personal dust collectors, continues to be critical to the long-term health of mine and open pit mines workers (Colinet, 2005). For these dust control systems to be monetized to its full potential, it is essential that their maintenance becomes part of routine practices. Management should encourage employees to regularly review the systems installed. An effective reduction of respirable dust exposure of workers should also contain a component of education and training. Workers should be aware of potential risks to health associated with exposure to respirable dust in excess.

Taken the fact that drilling operators in general have one of the highest exposure levels to respirable dust and the operator of the drill bits, being an employee who is at the top of the list of functions that have the highest exposure to respirable silica dust, (Randolph (2004), was one of the researchers studying dust generation from blasthole drills and developed a simple, quick fix system that reduces respirable dust concentrations by more than 63% at the dump point. This device, which requires almost no maintenance, is small and inexpensive, and it will help operators maintain compliance to the dust standard. The thought process was that a reduction of respirable dust at any of the multiple sources points on the drill, in this case the dust collector dump point, should reduce the total respirable dust generated by the drill. The drilling

machine generates high concentrations of respirable dust from several sources: drill table shroud leakage, dust leakage through the table bushing, dust discharge from the dust collector exhaust due to impaired filters, and dust entrained from the dust collector fines dumped onto the bench. Advantages to this method of respirable dust reduction are that the material is inexpensive and requires almost no maintenance. If the shroud becomes damaged, it can easily be replaced in 10-15 minutes requiring little, if any, downtime for the drill. To reduce the respirable dust concentrations at the collector dump point, the purpose of Randolph, was a piece of brattice cloth attached to the dust collector dump point using a large hose clamp. This dust shroud is installed over the existing rubber boot attached to the dust collector dump point. The length of brattice cloth (or similar material) should be sufficient to allow it to extend from the dust collector dump point to the ground. It should be cut so that it is only long enough to just touch the ground when the drill is lowered.

4.4. Health Effects

Throughout the literature review there is an evident link between exposure to crystalline silica dust and the its effect, in general harmful. Silicosis, the main illness resulting from exposure to this type of contaminant, can be defined as an occupational disease that results from prolonged exposure to crystalline silica dust. The inhalation of dust containing crystalline silica can be very harmful to human health, and may often be deadly if safety precautions are not used. It has plagued industry around the world since mankind began digging into the earth (Thomas, 2010).

According to Smith (Smith & Leggat, 2006), silicosis, asbestosis and coal workers' pneumoconiosis, represent the three of the most important occupational-related dust diseases in Australia.

To gain a clear picture of pneumoconiosis trends over time, a 24 year's retrospective analysis of national mortality data was performed for the period 1979 to 2002. Over 1.000 pneumoconiosis-related fatalities occurred during this time, 56% of which were caused by asbestosis, 38% by silicosis and 6% by pneumoconiosis. Between 1979 and 1981, silicosis accounted for 60% of all pneumoconiosis-related fatalities in Australia, followed by asbestosis (31%). By 2002 however, asbestosis was causing 78% of all fatalities, while silicosis accounted for only 19%. Asbestos-related mortality increased three-fold between 1979 and 2002, with a clear excess risk demonstration among male workers. On the other hand, mortality rates for mortality rates for silicosis and coal worker's pneumoconiosis declined significantly during the same time period. Overall, this study suggests that pneumoconiosis, particularly asbestosis, continues to be an important occupational disease in Australia.

To identify whether there is evidence of pneumoconiosis and other respiratory health effects associated with exposure to respirable mixed dust and quartz in United Kingdom opencast coalmines, Love (Love, et al., 1997), with a cross sectional study of current 1249 workers (1224 men, 25 women) was carried out at nine large and medium sized opencast sites in England, Scotland, and Wales. To characterize a range of occupational groups within the industry, full shift measurements of personal exposures to respirable dust and quartz were taken. Up to three surveys were carried out at each site, covering all four seasons. For the purpose of comparisons with health indices these groups were further condensed into five broad combined occupational groups. Full sized chest radiographs, respiratory symptoms, occupational history questionnaires, and simple spirometry were used to characterize the respiratory health of the workforce. The highest concentrations of quartz were found in groups of rock drilling and bulldozers drivers (used to move earth and stone of the coal seams). As their exposure is principally to dust from overburden that contains silica rather than coal, and as the exposures to respirable dust are far lower than the exposure to coalmine dust associated with coal workers' pneumoconiosis, it is likely that the pneumoconiosis represents silicosis. It can, therefore be concluded that exposure to airborne mixed respirable dust, particularly in the dustiest preproduction parts of the industry, can give rise to a small risk of radiological abnormalities, consistent with the characteristics of pneumoconiosis, probably silicosis. The dust conditions are not sufficient to cause notably reduced lung function or increased frequency of chronic bronchitis, nor are they positively associated with symptoms of asthma. However, the results point to a need for continuing vigilance to keep dust exposures low, particularly in those occupations of highest occupational risk.

Silicosis typically presents as a chronic disease after 10 or more years of exposure to crystalline silica dust (Checkoway, 1995). The existence of a quantitative relationship between exposure to quartz- α and silicosis risk, is well established (McDonald, 1995) (Donaldson et al., 1998).

Regarding the average age of workers ($31.6 \pm 1,9$ yr) and job seniority ($3.8 \pm 1,0$ yr), the author (Golbabaie, et al., 2004) concluded that workers are too young to have severe silicosis symptoms and therefore the likelihood of cough, phlegm, allergies and skin disorders are very low (Sanderson et al., 2000). As other research has shown, the symptoms appear after 10 years of professional experience, while workers analyzed in this study have a short history of seniority at work which leads to the conclusion that it is too early to find any relationship between concentration of quartz and respiratory symptoms and skin (Calvert et al., 1997). Exposure to crystalline silica dust may be responsible for the increased risk of developing tuberculosis and other respiratory diseases, contribute to kidney disease (Thomas, 2010) and other systemic autoimmune diseases, including scleroderma, rheumatoid arthritis, lupus erythematosus, and some sclerosis of small vessels with renal impairment. Studies on specific groups of professionals with high level of exposure to silica, as is the case of miners working underground or in open pit mines, showed increased rates of autoimmune diseases compared with the expected rates in the general population. The specific manifestation of this effect may depend on underlying differences in genetic susceptibility or other environmental exposures (Parks, Conrad, & Cooper, 1999).

The author (Hnizdo, 2003), in a review article on chronic obstructive pulmonary disease caused by occupational exposure to silica dust, explores the epidemiological and pathological evidence, considering this type of dust one of the most important occupational respiratory toxins. Epidemiological and pathological studies suggest that silica dust exposure can lead the worker to chronic obstructive pulmonary disease, even in the absence of radiological signs of silicosis, and that the association between cumulative silica dust exposure and airflow obstruction is independent of silicosis.

4.5. External factors enhancer's diseases linked to exposure to respirable crystalline silica dust.

Some authors point to some other factors that associated with exposure to silica may potentiate other diseases. According to Solt, the increased risk of developing rheumatoid arthritis is associated with workers' exposure to silica. However, the history of this disease reflects genetic and environmental factors such as the habit of smoking, but little is known about the influence of other factors. Actually it is known that factors such as age, residential area, and socioeconomic class as smoking habits were considered as potential confounders in the analysis of the association between silica exposure and rheumatoid arthritis (Stolt & Källberg, 2004).

Other authors (Jones, 2003), (Akbar-Khanzadeh & Brillhart, 2002) consider as confounding factors, the following parameters: speed and wind direction, relative humidity and ambient temperature, which are determined during dust sampling period. It appears that with increasing wind speed was a significant reduction in the concentration of silica dust. The fact that we are working against the wind, also contributes to the reduction of exposure to silica dust compared to wind in a favorable direction, however, the difference was not statistically significant.

In the study of Akbar-Khanzadeh (2002), the weighted average concentration of silica dust in 69% of the samples exceeded the recommended exposure limit (0.05 mg/m³ recommended by the American Conference of Governmental Industrial Hygienists - ACGIH, 2001), showing a strong need to developed methods to control workers exposure to crystalline silica dust.

Most of the authors surveyed, talk about the dust generated by machinery and equipment during the production process. Jones (Jones, 2003) makes the physical and chemical characteristics of the cloud of dust generated by the detonation of explosives in the dismantling of the massive, in a quarry in the North of Cardiff, Wales. From the study, it is confirmed the existence of three distinct clouds of dust, not only in terms of color of the projected cloud but also designed the cloud constituents and respective particle sizes, were examined within the quarry and the nearest village. So, the cloud that expanded even greater distance would be consisted mainly of mineral particles and should take the color of the stone quarry, was followed by a cloud of gray dust, mainly constituted of particles arising from the combustion of explosives, followed by a cloud of lighter color and located essentially in the detonation area. The samples were analyzed by high-resolution electron microscopy that found different sizes as the cloud of dust analyzed and the location of the sample. Thus, any consideration made in terms of adverse health effects of these dust clouds, it has to take account of these three components, wherever they locate sampling. The size distribution of dust corresponding to particles arising from the combustion of explosives, is below 2 µm and mineral dust transported by the first cloud have grain sizes above 2 µm, when analyzed in their travel outside the quarry, in the nearest village, dust sampled have a close size distribution. With this study it can be concluded that sampled dust in the nearest village, does not correspond entirely to dust generated at the quarry, but are caused by other industrial sources and aren't caused by the quarry, such as work on the surrounding roads, and others.

In that way, the literature research conducted until now, allows us to conclude that the substance of concern in evaluation - dust, crystalline silica is the one that has, for the type of industry under review, more papers with scientific interest evidenced, not only because the effects it would have on workers' health, but also because, together with other agents, become potential of various autoimmune diseases. As a consensual aspect, silicosis is an occupational disease that is preventable, but that has no cure. New cases of death from silicosis continue to occur, even in young workers. Currently, there is no effective treatment available (Thomas, 2010) (CDC, 2005), so the effective control of exposure to crystalline silica in the workplace is therefore crucial.

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