# OCCUPATIONAL EXPOSURE OF FREE SILICA DUST AND IMPAIRMENT OF RESPIRATORY STATUS: A REVIEW

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**Large numbers of industries, processing units and mines, where the occupational exposures of crystalline free silica dust are common. Although the fatality of silicosis was documented but studies on exposure level of free silica dust, prevalence of Silicosis and recommended level of free $SiO_2$ dust in India and other countries are not comprehensive. The silica dust exposure occurs in many industries, most of them are unorganized in nature, for which the data and statistics are also lacking. So, detailed collaborative studies are essential in India to reduce this occupational disease.**

Different types of dust can produce diverse effects on human lung such as fibrogenic, irritation produces, allergenic and carcinogenic effects. Basically crystalline silica is, fibrogenic (i.e., potent it produces fibrosis) in nature but a non-crystalline form of silica is non-fibrogenic (Townsend *et al.,* 2000).

Due to inhalation and deposition of crystalline silica particles in the lung's parenchyma, leads to silicosis. The most important factor, in the development of silicosis depends on the dose and percentage of respirable silica contained in the inhaling dust. Other important factors are particle size, the crystalline or non-crystalline nature of the silica, the duration of dust exposure and time period from first exposure to diagnosis of silicosis. Silica also causes many other serious health problems (Ampian, 1992; American Thoracic Society {ATS}, 1997).

***Silicosis:***

Silicosis is a progressive interstitial lung disease, characterized by shortness of breath, cough, fever and bluish skin; it can be divided in to three different forms (acute, accelerated and chronic) depending upon the air-borne concentrations of respirable crystalline silica and the duration of exposure:

I. Chronic silicosis is the most common type of silicosis. It results in fibrosis in the lungs and occurs after many years, usually 10–30 years of exposure, i.e. too much exposure of respirable crystalline free silica dust (Parker *et al.,*1998; Peters, 1986).

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II. Accelerated silicosis results from exposure of very high concentrations of respirable crystalline free silica dust over a relatively short period (5-10 years) of time (Parker *et al.*, 1998; Peters, 1986).

III. Acute silicosis is the most destructive and grave type of silicosis which develop from exposure of high concentrations of respirable crystalline silica dust over a period ranging from as little as a few weeks to 5 years (Parker *et al.*,1998;Peters, 1986).

**Patho-physiology of Silicosis:** There are a number of mechanisms by which the silica particles cause cell injury and lead to respiratory impairment. Silica particles can initiate toxic and inflammatory changes like increased production of oxidants, cytokines, chemokines and elastase. It can also causes epithelial cell injury and localized fibrosis (Hnizdo and Vallyathan, 2003).

In the year of 2012, U. S. Geological Survey department found that presence of silica 41% of the U.S. tonnage was used as hydraulic fracturing sand and well-packing and cementing sand, 26% as glass-making sand, 11% as foundry sand; 6% as other whole-grain silica; 6% as whole-grain fillers and building products; 3% as ground and ungrounded sand for chemicals; 2% as golf course sand; 2% for abrasive sand for sandblasting; and 3% for other uses (Federal Register, 1994).

***Table 1: Nature of different sectors, work places, occupational activities and sources of air borne free silica dust***

| Sl. No. | Nature of Sector | Work Place /Industry | Specific Activity/ Task | Source from which Free $SiO_2$ generated |
|---|---|---|---|---|
| 1 | Organised Sector | Mining and related milling operation | Occupations in underground, surface, mill and mines (metal and non-metal, coal) | Ores and associated rocks |
| 2 | Organised Sector | Glass (including fibre glass) manufacturing Industries | Raw material processing, Refractory installation and repair | Sand, crushed quartz, refractory materials |
| 3 | Unorganised Sector | Quarrying and related milling operations. | Crushing stone, sand and gravel processing, monumental stone cutting and abrasive blasting, slate work, di-atomic calcination | Sand stone, granite, flint, sand, gravel, slate, diatomic material of earth |
| 4 | Unorganised Sector | Construction Industries | Blasting of several structures, building highway and tunnel construction, excavation and earth moving, masonary, concrete work, demolition | Sand, concrete, rock soil, rock concrete, mortar, plaster materils |

| Sl. No. | Nature of Sector | Work Place /Industry | Specific Activity/ Task | Source from which Free SiO2 generated |
|---|---|---|---|---|
| 5 | Unorganised Sector | Ceramics, (including bricks, tiles, sanitary ware, porcelain, pottery and refractory) | Mixing, moulding, glazing and finishing. | Clay, shale, flint, sand, quartzite, di atomic material of earth |
| 6 | Organised Sector | Cement Industries | Raw material processing | Sand, clay, limestone |
| 7 | Organised Sector | Metal product producing factories ( including structural metal, machinery, transportation of equipments) | Abrasive blasting | Sand |
| 8 | Organised Sector | Iron and steel mills | Refractory preparation and furnace repair | Sand and refractory materials |
| 9 | Unorganised Sector | Automobile repairing | Abrasive Blasting | Sand |
| 10 | Unorganised Sector | Jewelry work shop | Cutting grinding, polishing, buffing | Semi-precious gems or stones |
| 11 | Organised Sector | Ship building and repairing | Abrasive blasting | Sand |
| 12 | Organised Sector | Boiler scaling | Coal-fired boilers | Ash and concretions |
| 13 | Organised Sector | Big Scale Silicon and ferrosilicon Foundries (ferrous and non-ferrous) | Raw materials handling, casting,shaking out, abrasive blasting, fettling, furnace installation and repair | Sand, refractory material |
| 14 | Unorganised | Small Scale Silicon and ferrosilicon Foundries (ferrous and non-ferrous) | Cutting, abrasive blasting, fettling, furnace installation and repair | Sand |

*Source: International Agency for Research on Cancer (IARC, 1997)*

***Global Scenario:***

Silicosis cases have been found worldwide. Silicosis burden is substantial globally. About 30-50% of workers engaged in primary and high-risk industries in developing countries suffered from the silicosis or other pneumoconiosis. Annually 30,000 people died due to pneumoconiosis caused by airborne particulate matters (WHO, 2007).

In developed countries matter like USA during 2001, 164 deaths and in 2010, 101 deaths were reported due to silicosis and 1.7 million workers were exposed to free silica dust out of which 10% workers were at risk to the disease (Thomas *et al.*, 2010). In West Virginia, Hawk Nest's (USA) silicosis were reported that out of 5000 workers 764 were dead and 1500 developed because of tunneling, blasting, and drilling activities (Centre for Disease Control and Prevention –(CDC, 2005). According to the summit on elimination of silicosis jointly organized by the WHO and ILO in 2003; around 3000 in Germany, Japan and Australia greater than 1000 cases were reported annually. In France, around 300 cases were reported. South Africa had 600,000 silicosis cases mainly mines workers (Marble Institute of America MIA) 2008). In Canada, amongst 400 gold miners (during 1925-26) 46 workers were diagnosed with the silicosis (Cunningham, 1930).

In developing countries situation is at alarming level. In China, more than 5 million workers were exposed to deadly free silica; and more than 24,000 deaths occurred due to silicosis from 1991-1995. In Brazil, more than 6.6 million exposed to silica; in Minas Girais province alone greater than 4500 people became the victim of the disease (Ferreira *et al.,* 2008). In Brazil's drought affected northeast, stone is found in layers with high silica content (97%), causing silicosis in 26% of the work force. A study conducted in Petropolis province in Brazil reported 53.7% silicosis amongst stone artisans (Antao, 2004).

In 2003, International Social Security Association reported that silicosis as the biggest occupational health challenge in Rwanda, East Africa. In Latin American countries, 37% of the miners suffered from the silicosis. In Columbia alone were around 1.8 million people at risk of developing silicosis (Luton, 2007).

The National Institute for Occupational Safety & Health (NIOSH), conducted another survey, showed that more than 100 people living in the United States died each year due to silicosis. Others were inflicted with the disease having experience of breathing difficulties and a reduced quality of life. Because of the potential for exposure to dust containing free silica in the mining and processing of industrial sands (Alehouse et al., 1995). Continuous exposure to stone dust can cause abnormal alterations in the normal levels of Serum Glutamate Pyruvate Transaminase (SGPT), Alkaline Phosphatase (ALP), bilirubin and creatinine (Ilahi *et al.,* 2012).

Ikeda *et al.* (2003) in Kyoto, Japan examined that the mortality due to tuberculosis and cancer in the lungs was elevated in a cohort of 200 male stone cutters by the exposed of air born free silica dust. Among the 200 cohort members, 99 men deceased during the observation period, the deaths including 10 cases of lung tuberculosis (of which 9 cases had silicosis together), 20 cases of all malignancies, and 6 cases of lung cancer (5 cases with silicosis).

Study in cement industry in Pakistan revealed that lung functions in workers were significantly impaired due to dust exposure containing crystalline silica and in long term, the response correlate with years of exposure (Sultan *et. al.,* 2013). In another study showed that significantly lower $FEV_1$% and $FEF_{25-75}$ and higher FMFT, reduced $FEV_1$ % with increasing level of dust exposure and higher prevalence of respiratory symptoms those who are exposed by cement dust containing crystalline silica. So, exposure to dust in the cement factory leads to higher incidence of respiratory symptoms and impaired lung function (Noor *et al.,* 2000).

Rotary drill operators, front-end loader operators, truck drivers, and crusher operators are permanently exposed to stone dust. Stone dust contains free silica, lead, asbestos and airborne solids, etc. Coarse airborne particles have been shown to have an adverse effect on health (Brunekreef *et al.,* 2005).

The exposure to respirable silica dust from silica grinder was more than 10 times higher than the threshold limit and caused a high prevalence of respiratory symptoms and lung function disorders among mills workers in flour factory (Zamani *et al.,* 2013).

In 1974, National Institute of Occupational Safety and Health (NIOSH) was established and recommended exposure limit of 0.05 mg/m$^3$during 10-hours Time Weighted Average (TWA) for respirable crystalline silica to prevent the risk of silicosis from occupational exposure. In 2005, the American Conference of Governmental Industrial Hygienist (ACGIH) has revised the crystalline silica exposure limit by adopting a Threshold Limit Value (TLV) of 0.025 mg/m$^3$ for all three common forms of crystalline silica (quartz, cristobalite, and tridymite). The Mine Safety and Health Administration (MSHA) and Occupational Safety and Health Administration (OSHA) had established the exposure limit for respirable dust that contains quartz, expressed in milligrams per cubic meter and determined the formula: Quartz PEL = 10 ÷ (% Quartz + 2). The Permissible Exposure Limit (PEL) is applied to respirable dust containing quartz; the concentration of quartz is limited to approximately 0.1 mg/m$^3$. The amount of dust inhaled per day, percentage of crystalline free silica in the inhaled dust, size of the particles and length of exposure, all play its role in the onset of silicosis, Workers engaged in mining, hard coal, gold, cutting of sand stone and granite, sand blasting, in the manufacture of silica abrasives and foundry operations are commonly exposed in the silica dust (NIOSH, 1992).

***Indian Scenario:***

In many low to middle income countries, including India, silicosis continues to be an occupational health hazard. India has a large mining industry, concentrated in the states of Chhattisgarh, Jharkhand, Orissa and West Bengal, (Center for Disease Control and Prevention (CDC), 1995).Silica is abundant in nature and composes about 12% of the earth's crust. It is responsible for causing the oldest and most dreaded of occupational diseases, silicosis (Chattopadhyay *et al.,* 2006).

***Organized Sector:***

In 1999, the Indian Council of Medical Research, (ICMR) reported that around 3.0 million workers were at high risk due to exposure to free silica; of these, 1.7 million workers in mining or quarrying activities, 0.6 million in the manufacturing of non-metallic products (such as refractory products, structural clay, glass and mica) and 0.7 million in the metals industry in India. There were also around 5.3 million construction workers at risk of silica exposure (Gupta, 1999).

In India, there were about 3 million workers employed in the formal economy with potential exposure to silica dust. Approximately 8.5 million more workers in construction and many more in the informal sectors were exposed to silica dust. Thousands of these workers developed silicosis every year and dead directly from it, or from secondary cause such as TB or lung cancer. A few of these deaths were recorded as being caused by silicosis or as being work-related lung diseases in national statistics (Chattopadhyay, 2006). Due to variations in silica concentrations and duration of exposure in the work environment the reported occurrence of silicosis in India ranges widely from 3.5% among 1977 workers in an ordnance factory to 54.6% in 593 workers in the slate-pencil industry (Viswanathan *et al.,* 1972).

The Systolic and Diastolic blood pressure was found to be higher among the workers who were exposed by cement dust having crystalline free silica dust, than un-exposed cement mill workers, which were statistically significant. A significant increase in weight among exposed group also identified. Maximum 29 (45.3%) of the workers had stuffy nose when compared to unexposed with Relative risk (RR) of 2.6, followed by dermatological complaints and lower respiratory complaints with RR of 2.18 and 2.3 respectively (Manjula *et al.*, 2013).

A cross-sectional study was carried out in the years of 2014-16 among the steel foundry workers in the district Burdwan, West Bengal, India. They showed that the non-smokers foundry workers (Group II) were suffered from respiratory problems with aggravating conditions than that of the smokers foundry workers (group I), though the working time were 8 hours in both the groups. They concluded that the foundry workers may have the prevalence of occupational asthma or COPD; Other signs and symptoms included wheezing, coughing, shortness of breath, etc. (Paine *et al.,* 2017).

***Unorganised Sector:***

A study in 1992-94 was carried out by the Desert Medicine Research Center, Jodhpur, reported that 9.9% sandstone workers had suffered from silicosis. This study revealed that around 10% mines workers were suffering from the silicosis (Sishodiya *et al.*, 2014).

Another study conducted in 1996, in sandstone mines in Jodphur. Two hundred eighty eight ( 288) workers were examined for occupational diseases, 14% were found to be suffering from severe silicosis, and 28% were found to be suffering from silicosis of less severity (Malik, 2005).

An epidemiological survey was conducted where six villages with a population of 6975 were taken as subjects. Around1288 cases were diagnosed provisionally (till August 2016) in the entire district by the private Occupational Health Specialist located in Jaipur and the District Tuberculosis Officer (DTO) located in Karauli district headquarters. Out of 1288 cases, 687 cases of Silicosis were presented before the Pneumoconiosis Medical Board (PMB), Jaipur; they confirmed 601 cases for having Silicosis (Shamim *et al.,* 2017).

A study of silicosis revealed that 22.4% stone quarry workers were having evidence of silicosis. About 32% workers showed radiological evidence of tuberculosis. Majority of the cases of silicosis were detected among workers who had exposure over 10 years. The mean total dust concentrations in two quarries were 3.38 and 3.72 $mg/m^3$ and respirable dust concentrations in two quarries were 0.80 and 0.85 $mg/m^3$ respectively. The free silica content in dust was estimated to be about 70% (NIOH, 2011). It is suggested that the prevalence of silicosis amongst stone quarry workers was 21% and that in stone crusher was 12% (Saiyed *et al.,* 2004).

A survey in sand stone mines located in lalitpur district of Uttar Pradesh revealed that the total and respirable dust concentration during the process of stone cutting were 22.4 $mg/m^3$ and 1.6 $mg/m^3$ respectively. Examination of 125 stone cutters showed that the prevalence of silicosis and tuberculosis were 22% and 48% respectively. The total and respirable dust levels after installation of the control device, which operates on the principle of enclosure, were 3.4 mg/ $m^3$ and 0.8 mg/ $m^3$ respectively (Kashyap, 1994).

In 2006, a survey was conducted by Khedut Mazdoor Chetna Sangath (henceforth Sangath), a local union of peasants and workers, with the assistance of Shilpi Kendra, an Indore based NGO working on public health, found that another 21 people had died in Malvai village, Gujrat. By May, in the next year, another 12 had died, bringing the total number of fatalities to 38. From the 23 families whose members went to work in the stone-crushing units in Gujarat, only four adults survive.The cause for this incidents they suggested for the exposure of silica dust was in concentrations 81mg/$m^3$ and 660 times higher than the threshold limit value considered as the international standard (Shilpi Kendra, 2007).

Evaluation of health status of resident who had worked in stone crushers and quarries, showed that approximately 39% of the subjects examined were suspected to be suffering from silicosis, or silico- tuberculosis while the number of subjects with tuberculosis was 29%. (Centre for Occupational and Environmental Health, 2005).

National Institute of Miners Health (NIMH) in collaboration with Association for Rural Advancement through Voluntary Action and Local Involvement (ARAVALI) evaluated the medical records of 93 subjects suffering from various respiratory problems and with the history of work in stone mines. They observed that 78.5% of subjects have evidence of silicosis of which 21.9 % had Progressive Massive Fibrosis (PMF). Majority of the subjects were suffering from advance stage of silicosis and 26.8% of workers had radiological evidence of pulmonary tuberculosis and 23.2% of subjects with silicosis had coupled with tuberculosis. On the basis of assessment of records, they concluded that many workers were engaged in stone mining area may be suffering from silicosis and associated tuberculosis (National Institute of Miners Health, 2011).

The Supreme Court of India while hearing a writ petition (Civil No. 110/2006; People's Rights and Social Research Centre (PRASAR) vs Union of India and Others), passed an interim order on 5 March 2009, whereby it issued directions to the Union Ministries of Health and Labour. A complainant, in the initial report that 83 persons were found to be suffering from silicosis and 55 persons had died due to this disease. ( National Human Right commission, NHRC, 2016).

***Table 2: Hazardous sectors and prevalence percentage of silicosis in India***

| Sl No. | Authors/Organisation and Year | Industries/ Work Places | Prevalence Percentage of Silicosis |
|---|---|---|---|
| 1 | Caplan and Burden, 1947 | Gold Mines | 8.84 |
| 2 | Gowda, 1983 | Gold Mines | 13.9 |
| 3 | Chief Advisor of Factories, 1953 | Mica Mines and Mica Processing Industries, Bihar | 34.0 |
| 4 | Ministry of Labour, (GOI), 1960 | Manganese Mines | 4.1 |
| 5 | Chief Advisor of Factories, 1961 | Lead and Zink Mines in Rajasthan | 30.4 |
| 6 | Saini et al., 1984 | Stone cutters, Kashmir | 20.0 |

| Sl No. | Authors/Organisation and Year | Industries/ Work Places | Prevalence Percentage of Silicosis |
|---|---|---|---|
| 7 | Sethi and Kapoor, 1982 | Stone cutters | 25.0 |
| 8 | Gupta et al., 1972 | Stone Cutters | 35.2 |
| 9 | Samal et al., 1986 | Foundries Workers | 27.2 |
| 10 | Viswanathan et al., 1972 | Ordnance Factory | 3.5 |
| 11 | Sadhu et al., 1995 | Agate Workers | 38.0 |
| 12 | Srivastava et al., 1988 | Glass Bangle | 7.3 |
| 13 | Saiyed et al., 1985 | Slate Pencil Workers | 54.6 |
| 14 | Gangopadhyay et al., 1994 | Mica mines and mica processing | 5.2 |
| 15 | NIOH, 1986 | Quartz Crushing | 12.0 |
| 16 | NIOH, 1987 | Stone quarry | 22.0 |
| 17 | NIOH, 1989 | Sand Grinding | 27.8 |
| 18 | Saiyed et al., 1995 | Ceramics & Potteries | 15.1 |

Source: Indian Council of Medical Research, (ICMR, 1999)

***Preventive Measures:***

In 1995, the World Health Organization and the International Labour Organization 120 began a public awareness and prevention campaign to eliminate silicosis from the world by 2030. Several countries like Brazil, Chile, China, Indonesia, Malaysia, Mexico, Poland, South Africa, Thailand, Turkey, Ukraine, the Bolivarian Republic of Venezuela and Vietnam have established national programmes for the elimination of silicosis (WHO, 2007).

The National Industrial Sand Association (NISA) recommended Silicosis Prevention Program (SPP) consists of the following seven elements: 1) Management Commitment to Implementation; 2) Occupation Health Program Implementation; 3) Medical Surveillance; 4) Dust Exposure Assessments; 5) Dust Control; 6) Employee Involvements; and 7) Smoking Cessation Program (OSHA, 2004).

The filtration properties of Indian fabrics were measured using modified respiratory protective device (RPD) tests, to match conditions in Indian quarries. Results were compared to those of dust masks meeting Australian and International standards. Four layers of loose weave fabrics were found to perform best, but would still be insufficient for use at sites with highly hazardous dusts (Benton, 2012).

A study was undertaken to investigate the potential risk factors, and to understand the mechanism of silica-induced toxicity among agate workers. Out of 82 agate workers studied the majority (55%) were aware about the silicosis, harmful effect of silica-dust exposure (72%), protective methods to avoid silica-dust exposure (80%), but only 22% workers were using the protective methods. The data suggest that apart from the awareness, the education level of workers also plays a significant role to use the protective methods (ICMR, 2012)

This chronic and progressive lung disease has no effective treatment. Patients can only be provided supportive care. In some cases, lung transplantation may be the only option left. The disease may continue to progress even after cessation of the exposure to silica dust. Depending on severity of the disease, it causes morbidity, disablement and deaths. Since there are no effective treatment to either, reverse the lesions or slow down its progression, hence preventive measures are the only solution to the problem (Bang *et al.*, 2015).

***Table 3: Sector/Work place wise recommended preventive measures and remedial strategy for the prevention of silicosis in India.***

| Sl. No. | Sector | Work Place /Industry | Recommended Preventive measures and Remedial Strategy |
|---|---|---|---|
| 1 | Organized | Mining and related milling operation | Safety measure should have to follow, i.e. engineering control as well as administrative control is recommended |
| 2 | Organized | Glass ( including fiber glass) manufacturing Industries | PPE's, respiratory mask, minimization of duration of work. |
| 3 | Un-Organised | Quarrying and related milling operations. | Periodic water sprinkling, use of PPE i.e. Indian Standard (IS) respiratory mask is recommended.**But there is nospecific preventive measures or remedial Strategy recommended.** |
| 4 | Un-Organised | Construction Industries | Periodic water sprinkling at work place, use of PPE i.e. Indian Standard (IS) respiratory mask is recommended. |
| 5 | Un-Organised | Ceramics, (including bricks, tiles, sanitary ware, porcelain, pottery and refractory) | Periodic water sprinkling at work place, use of PPE i.e. Indian Standard (IS) is recommended respiratory mask. |
| 6 | Organised | Cement Industries | PPE's, respiratory mask, minimization of duration of work. |
| 7 | Organised | Metal product producing factories (including structural metal, machinery, etc.) | Safety measure should have to follow, i.e. engineering control as well as administrative control is recommended |
| 8 | Organised | Iron and steel mills | Use of PPE i.e. Indian Standard (IS) recommended respiratory mask |
| 9 | Un-Organised | Automobile repairing | Periodic water sprinkling at work place, use of PPE i.e. Indian Standard (IS) is recommended respiratory mask |
| 10 | Un-Organised | Jewellery work shop | Use of PPE i.e. Indian Standard (IS) is respiratory mask is recommended respiratory mask. |
| 11 | Organised | Shipbuilding and repairing | Engineering control as well as administrative control is recommended |
| 12 | Organised | Boiler scaling | Engineering control as well as administrative control is recommended |
| 13 | Organised | Big scale Silicon and ferrosilicon Foundries (ferrous and non-ferrous) | Periodic water sprinkling at work place, use of PPE i.e. Indian Standard (IS) respiratory mask is recommended respiratory mask |
| 14 | Un-Organised | Small Scale Silicon and ferrosilicon Foundries (ferrous and non-ferrous) | Use of PPE i.e. Indian Standard (IS) is respiratory mask is recommended respiratory mask. |

Source: Indian Factory Acts (1948).

Therefore, a preodical survey and study are needed for the monitoring of the work environment in those work places where free silica hazards persist. Regular health cheak-up (respiratory and x-ray) is mandatory for identification of disease like Silicosis in regular interval, also specific preventive measures have to be formulated for the unorganised workers.

## CONCLUSION

However, from the literature it can be concluded that silicosis is a global phenomena. In India and other developing coutries, most of the workers in unorganised rarely have any means to social or job security. They are left unattended after they fell ill due to occupational exposure. In this review, it has reflected that the workers are regularly exposed to the free crystalline silica dust in the silica prone industries through out the world but prevalence data is inconclusive. So, detailed collaborative study is required to reduce morbidity and mortality of silicosis.

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