Dust masks for Indian quarry workers: A comparative analysis of the filtering efficiency of fabrics

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ABSTRACT: *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.*

1 INTRODUCTION

Through the industrial revolution and into the past decade, a greater awareness and understanding has been gained regarding the health effects of breathing fine dust particles. In Australia, the long-term effects of asbestos in the respiratory system have been widely publicised in recent years and exposure standards are now in place to protect Australian workers from dust-related respiratory illnesses (National Occupational Health and Safety Commission, 1995).

1.1 Standards and legislation

While strict and effective standards are in place to protect workers in Australia, the situation in India is very different. The few standards and little legislation which do exist are rarely enforced or regulated, resulting in dangerous working conditions for those exposed to high levels of fine dust (K Wood 2011, pers. comm., 11 March). Workers in mines and stone quarries are particularly at risk, with many dying of silicosis or other respiratory illnesses each year (Madhaven, 2009).

In India, National Ambient Air Quality Standards have been in effect for some time, defining the maximum allowable levels of particulate matter in the air in both industrial and 'ecologically sensitive areas' (Central Pollution Control Board, 2009). However, reports from the Indian Government have shown that these levels are not usually met (Central Pollution Control Board, 2006). The *Environment (Protection) Act 1986* with its subsequent rules and amendments include standards for implementing dust control measures, such as dust suppression, wind breaking and water spraying (Bhawan, 2009).

The *Factories Act 1948* applies to stone crushing processes and similarly stipulates that effective measures must be taken to prevent inhalation of excessive concentrations of dust. Amendments to this legislation also specifically set the Permissible Exposure Limit of respirable silica at 0.1 mg/m^3, in line with exposure limits for Australia (Commonwealth of Australia 2010), the United States (U.S. Department of Labor, 2011) and many European countries (IMA Europe, 2007).

1.2 Health risks

The health issues related to breathing respirable dust vary widely depending on the type of dust involved and the concentration inhaled. Pneumoconiosis, the general term given to a range of lung diseases caused by breathing dusts, typically causes chest tightness, shortness of breath and coughing (Encyclopædia Britannica, 2011). Under continued exposure it may develop into chronic bronchitis (inflammation of the bronchi) or emphysema (destruction of lungs over time) (National Center for Biotechnology Information 2010, 2011a).

Silicosis is the most likely form of pneumoconiosis to be dangerous to mine and quarry workers. Silica, or silicon dioxide (SiO_2), is extremely common in rocks and ores, particularly as quartz or sand. Silicosis is contracted by breathing respirable silica dust in one of its pure crystalline forms. As a result, crushing or blasting rocks with crystalline silica present is likely leave nearby workers at high risk of contracting the disease.

There are three types of silicosis, depending on the level and duration of exposure. These are (National Center for Biotechnology Information, 2011b):

- Simple chronic silicosis – from small concentrations over long periods (20+ years)
- Accelerated silicosis – from higher concentrations over mid-range periods (5-15 years)
- Acute silicosis – from extremely high exposure over very short periods.

Progressive fibrosis (scarring of lung tissue) is most common in accelerated silicosis, but is also likely from the simple chronic form. Once fibrosis has been established, it is irreversible (Murray et al, 2010). Treatment can only slow the progression, so exposure should be prevented wherever possible. Silicosis has also been linked to a range of other lung disorders (American Thoracic Society, 1997; Patel, 2009). Tuberculosis, a contagious lung infection, has been strongly linked to silica exposure, with reports of tuberculosis being from 2 to 30 times more common in silica exposed workers (Cowie, 1994; Sherson & Lander, 1990). The International Agency for Research in Cancer has listed silica as carcinogenic to humans, but some authors claim high smoking rates amongst workers would have affected previous findings (International Agency for Research in Cancer, 1996; Wong, 2002; Pelucchi et al. 2006). Some non-lung diseases, such as rheumatoid arthritis and renal disease have also been associated with silicosis (American Thoracic Society, 1997). It has been suggested that clay dust can also cause fibrosis, but usually requires long-term exposure to have serious effects (Encyclopædia Britannica 2011). Kaolin, or china clay, has been the subject of numerous studies on the issue, with links identified as early as 1948 (United Nations Environment Programme, 2005; Sheers, 1989).

Altekruse et al (1984) studied the level of kaolin dust exposure with the prevalence of fibrosis, and took the effect of smoking into account. They found that pneumoconiosis only occurred amongst workers who were exposed to the highest levels of kaolin dust, and that the effects of kaolin pneumoconiosis were minimal.

A survey of 70% of china clay workers in the United Kingdom by Rundle et al (1993) concluded that only under long-term exposure (~42 years) at the most dusty of common exposure levels would kaolin cause severe fibrosis.

1.3 The situation in India

Despite defined standards in India, the lack of enforcement and education about the dangers of respirable dust means that many people work and live in highly dangerous conditions. Sivacoumar et al (2006) found that the total suspended particulate concentration on these sites can be as high as 1.706 mg/m^3. The families of workers often live on or near the worksite, so women and children are also exposed to high levels of potentially dangerous airborne dust.

It has been shown (Bhawan, 2009; Lahiri et al, 2005) that the most cost effective way to address dust exposure is by implementing engineering controls which trap and collect dust at its source. To prevent the dust which does become airborne from harming workers' lungs, Australian and International standards state that respiratory protective devices (RPDs) should be used as an important last resort against airborne contaminants (Joint Australia/New Zealand Standards Committee, 2009; International Organization for Standardization, 2010). Most workers in India do not usually wear any form of face mask, while others drape silk or cotton scarves around their faces in an attempt to reduce irritation. Any benefit these scarves may provide is often counteracted by a poor facial seal – air flowing around the scarf will carry dust with it.

The prevalence of silicosis in India has not been accurately measured, and the consolidated number of diagnosed cases is simply not available (Srivastava & Fareed, 2009). However, various estimates have been made as to silicosis prevalence in particular industries or regions. Saini et al (1984) reported 20% prevalence amongst stone cutters in Kashmir, while Sethi & Kapoor (1982), and Gupta et al (1972) claimed higher nation-wide estimates within the stone-cutting industry: 25% and 30% respectively. The Indian National Institute of Occupational Health (NIOH) (1987) reported 22% prevalence of silicosis in stone quarry workers in 1987, and since 2002 have completed studies showing that the levels of silica in stone crushing workplaces were so high that only six months of work was sufficient to cause silicosis (Patel, 2009).

While accurate statistics are not readily available about overall prevalence of silicosis in India, there are many reports of deaths and illness from silicosis from across the country (Patel, 2009; Choudhury, 2010). According to Patel (2009), every state in India has reported cases of silicosis. He also claimed that in one village, every second quarry worker was reported to have symptoms of silicosis or tuberculosis, and 60% of beds in a hospital in Guntur, an industrial stone-crushing city, were occupied by silicosis affected patients.

Compounding the problem in India is that silicosis is often misdiagnosed as tuberculosis (Choudhury, 2010). Doctors prescribe antibiotics and send people home, where their condition deteriorates and may lead to death.

It is clear that dust suppression and filtering technologies are desperately needed to improve the health of workers in India and protect them from this potentially fatal lung disease.

This work was conducted in conjunction with Kristen

Wood, a volunteer with Engineers Without Borders, working with Santulan, an NGO based in the Indian state of Maharashtra. The work was designed to improve the occupational health and safety of workers in quarry sites. This work aims to address the lack of RPDs at these sites by investigating the filtration properties of fabrics readily and affordably available in the region. The parameters for the experiment were chosen with respect to a case study site in Pune, Maharashtra.

Results were limited by the precision of measurement equipment, leading to potentially high percentage error in returned values. Multiple measurements were taken to minimise this error where possible.

2 METHODOLOGY

Modified versions of standard RPD tests were run which closely matched the typical conditions in Indian quarries. A vacuum pump was used to pull air from a dusty environment through the test fabrics. This dusty environment was contained within a box with a circulation fan to keep the dust suspended, and samples were mounted inside the box, over a port to the vacuum equipment. Various pieces of measuring equipment were connected between the vacuum pump and the sample to measure its performance and control the rate of flow. These included a valve, vacuum gauge, flow meter and a secondary filter. The secondary filter consisted of 20 g of glass beads, housed within tubing adapters.

Dusty air was passed through each of the eight test fabrics at 100 L/min for two minutes. Three commercial-grade respirators were also tested for comparison. The mass of the samples and secondary filter before and after the test was measured, as was the change in flow as dust accumulated on the samples. The ratio of penetrating dust to total dust captured was calculated to evaluate the efficiency of the samples.

Initially, two layers of fabric were used in each of the tests, oriented so that the fibres were orientated at 45° to each other. Based on the results of these tests, samples with four layers of a loose weave fabric were also tested, as well as a sandwich structure of two loose weave layers enclosed between two medium weave layers. One gram of dust was used in each test, placed within the dust box with inner dimensions of 306 x 276 x 306 mm.

Both the dust and test fabrics were taken from the quarry Wood was working at, according to what was readily available in the region. In addition to the fabric testing, the dust sample was analysed by X-ray diffraction (Siemens 6000 X-ray Diffractometer) and scanning electron microscopy (Zeiss UltraPlus FE-SEM).

3 EVALUATION

The filtration efficiency tests showed that some fabrics would be certainly unsuitable for use as RPDs, but further tests may be required to determine if others may provide adequate substitutes for commercial-quality masks. As shown in figure 2, the penetration varied with the weave tightness, while the material and weave type did not seem to affect the filtration properties. While the tight weave fabrics filtered the dust reasonably effectively, their flow drop was very high. This indicated that they were quick to clog with dust, and if used as a mask would rapidly become very difficult to breathe through.

Based on its low flow drop value, the loose twill weave fabric was tested again, with four layers in each test. This had a much lower penetration value, whilst maintaining reasonable flow over the duration of the tests. The commercial-grade masks were typically made of a thick, loose weave material between two thin, tighter weave layers to hold this in place. The 'sandwich' design of two loose weave layers between two moderate weave layers was also

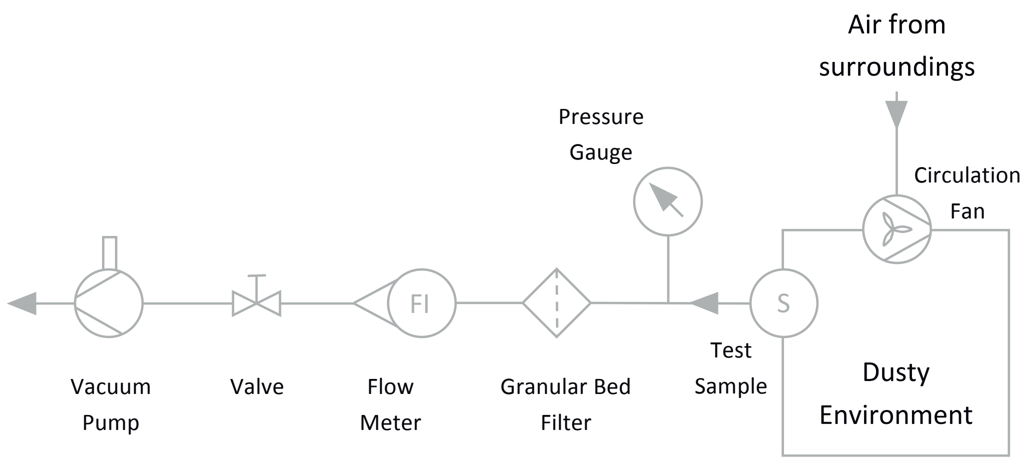

Figure 1: Piping and Instrumentation Diagram (P&ID) of setup.

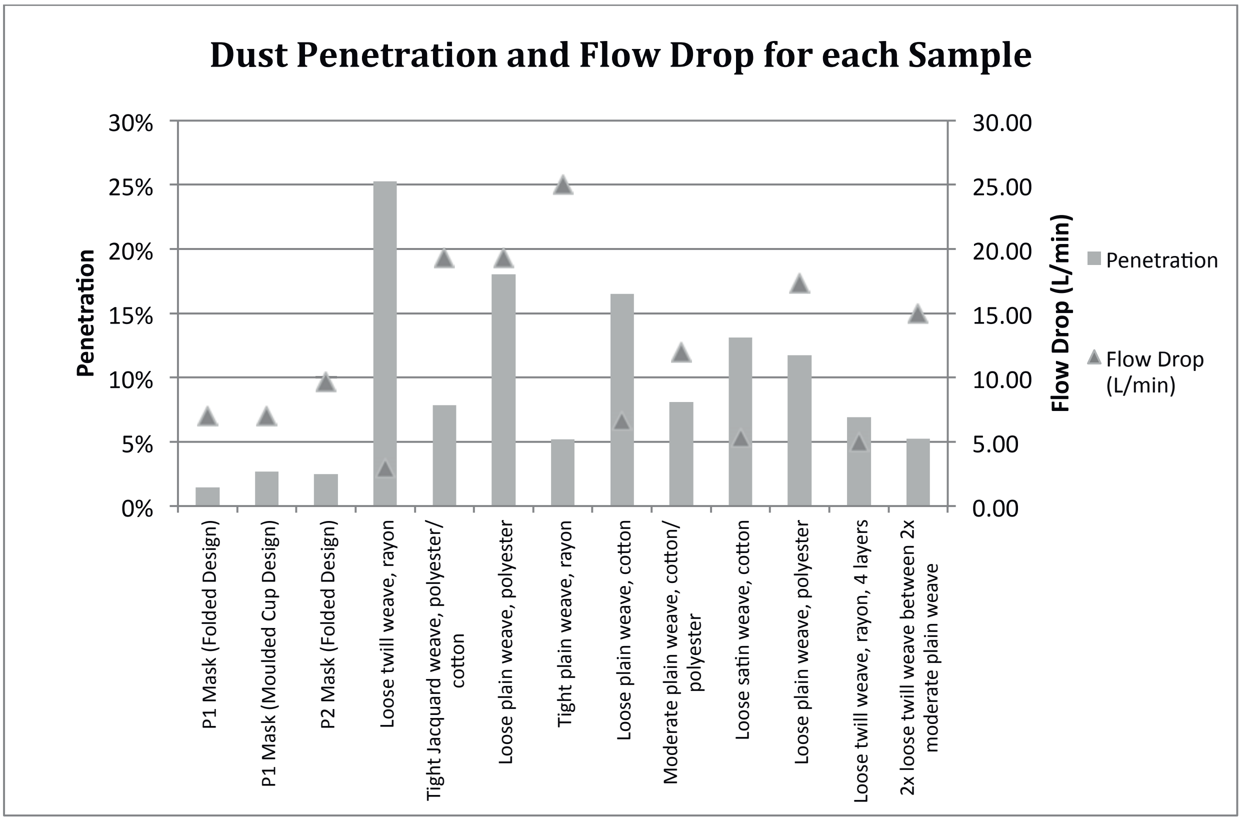

Figure 2: Penetration and flow drop of each sample.

tested in the hope of obtaining similar results. While the penetration value for this combination was quite good, the drop in flow was too high to be practicable.

Analysis of the dust sample indicated that there was no crystalline silica present, and that the material was likely to be a form of clay. This is likely to be relatively harmless to the human body at reasonable concentrations.

4 CONCLUSIONS

This work has shown that some fabrics would not be suitable for use in designing simple dust masks, while others may be found to be appropriate after additional testing.

Fabrics with tight weaves provided far too much breathing resistance when dirty, as dust filled small spaces between the fibres and obstructed air flow. Many layers of loose weave fabrics may provide similar efficiencies with less resistance, as alternative paths through the material will be available as others fill with dust. Loose fibres will also help bridge the gap between threads and improve the efficiency of the filter.

Similarly, cotton and other natural fibres may make better filters: the random curl of natural fibres may contribute to threads which are less dense, and also bridge gaps between each other, providing good filtration efficiency with minimal obstruction of air flow.

Simple water spraying or dust extraction systems may be sufficient for use at the case study site, with masks using the four-layer loose weave fabrics as a secondary measure. For use at sites with crystalline silica present in the dust, better performing masks would need to be identified.

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