Environ Monit Assess (2011) 178:449–454
DOI 10.1007/s10661-010-1703-1

Evaluation of exposure to the airborne asbestos in an asbestos cement sheet manufacturing industry in Iran

Davood Panahi · Hossein Kakooei · Hossein Marioryad · Ramin Mehrdad · Mohammad Golhosseini

Received: 10 May 2010 / Accepted: 6 September 2010 / Published online: 18 September 2010

Abstract Iran imports nearly 55,000 tons of Chrysotile asbestos per year and asbestos cement (AC) plants contribute nearly 94% of the total national usage. In the present study, airborne asbestos concentrations during AC sheet manufacturing were measured. The fiber type and its chemical composition were also evaluated by scanning electron microscopy (SEM), with energy-dispersive X-ray analysis. Airborne total fiber concentrations of 45 personal samples were analyzed by phase contrast microscopy. The results have highlighted that 15.5% of samples exceed the threshold limit value (TLV) established the American Conference of Governmental Industrial Hygienists, which is 0.1 fiber per milliliter (f/ml). Personal monitoring of asbestos fiber levels indicated a ranged from 0.02 ± 0.01 to 0.16 ± 0.03 f/ml. The geometrical mean was 0.05 ± 1.36 f/ml, which is considerably lower than the TLV. SEM data demonstrate that the fibrous particles consisted, approximately, of Chrysotile (55.89%) and amphiboles (44.11%). We conclude that the industrial consumption of imported Chrysotile asbestos is responsible for the high airborne amphibole asbestos levels in the AC sheet industry. More research is needed to improve characterization of occupational exposures by fiber size and concentration in a variety of industries.

Keywords Airborne asbestos · Asbestos cement sheet · Chrysotile and amphibole asbestos · Iran

D. Panahi · H. Kakooei (✉) · H. Marioryad · M. Golhosseini
Department of Occupational Health, School of Public Health, Tehran University of Medical Sciences, 009821 Tehran, Iran
e-mail: hkakooei@sina.tums.ac.ir

R. Mehrdad
Department of Occupational Medicine, School of Medicine, Tehran University of Medical Sciences, Tehran, Iran

Introduction

It is well known that all types of asbestos fibers may lead to malignant diseases such as lung cancer, but amphiboles, especially tremolite, amosite, and crocidolite, are responsible for mesothelioma (Nicholson and Landrigan 1994; McDonald et al. 1997; Kakooei and Marioryad 2010). By the mid-1960s, it was evident that airborne asbestos was a serious public health hazard that could cause asbestosis and many types of neoplasms (Sullivan and Krieger 2001). Asbestos fiber size and shape distributions have been indicated to vary between processes and operations, and data from previous studies suggest that long, thin fibers have greater carcinogenic potency than shorter, wider fibers (Dement and Wallingford 1990; Lippmann 1988). Asbestos is the commercial name given to a group of six related polysilicate fibrous minerals that are easily separated into very thin and flexible fibers when processed (Kakooei et al. 2007, 2009). These minerals are divided into two groups: serpentine (chrysotile) and amphiboles (crocidolite, amosite, tremolite, actinolite, and anthophyllite) (Kakooei et al. 2009). Asbestos has been used extensively in industrial materials, including Asbestos Cement (AC) sheets (Corrugated Roofing Sheets or CRS), AC pipes, automobile brake and clutches, vinyl asbestos floor, textured paints, thermal and electrical insulation boards, adhesives, and ventilation ducts (Kakooei et al. 2009; Kakooei and Marioryad 2010). Chrysotile (White asbestos) constitutes 98% of the world's production of this commercial product. To present day, about 20–40% of adult persons are thought to have held jobs that could entail some occupational exposure to asbestos (Goldberg et al. 2000). The use of asbestos in Iran began in the 1950s, and by the mid-1960s, it was widely cement materials (Kakooei et al. 2007; Kakooei and Marioryad 2010). There are ten AC sheets manufacturing facilities in Iran which employ approximately 3,000 workers. Iranian AC sheet (CRS) manufactures import all their chrysotile from Russia, Canada, China, and Kazakhstan. Today, the use of asbestos in Iran has not declined and the imports for 2007 were estimated to be 55,000 tons (Kakooei and Marioryad 2010). About 30,000 tons of chrysotile is used annually to produce AC sheets (CRS) in the Islamic Republic of Iran. Although there has been a few report on airborne asbestos concentrations in the automobile brake and clutch manufacturing industry (Kakooei et al. 2007; Kakooei and Marioryad 2010), there have been no reports on occupational exposure to asbestos in AC sheet production plants. Given this lack of data on asbestos concentrations in this industry and that asbestos has been used for about 60 years in Iran, an evaluation of workplace concentrations was urgently needed to provide the information necessary for planning of a national program aimed at banning use of. In Iran, there is currently no specific national standard for occupational exposure to asbestos. The American Conference of Governmental Industrial Hygienists (ACGIH) threshold limit value for respirable asbestos is 0.1 PCM f/ml (ACGIH 2008). Aims of this study were: (1) to determine airborne asbestos fiber concentrations by phase contrast microscopy (PCM) in different locations of a AC sheet manufacturing factory in a developing country; (2) and to compare the elemental compositions of asbestos for determining airborne asbestos types by SEM.

Methods and materials

Profiles of factory

This study was conducted at an AC sheet plant in Kerman, Iran, from June 2009 until April 2010. The factory started production in 1993. It currently employs 120 workers and produces 60,000 tons of AC sheets annually. The mean age (range) of the workers (male) was 41 (29–56) years. The mean employment period (range) of the workers was 15 (7–17) years. Asbestos-free substitutes were not used in the AC sheet products at the time of this study. In this factory, the AC sheets are manufactured by a wet process. The factory has six major processes: feeding of raw materials, mixing, molding of sheets, unloading cars, cutting, drilling, and sheet storage. The raw materials used in the factory are chrysotile asbestos (20%) and cement (80%). The main process and operations carried out during AC manufacture are mixing, molding, cutting, drilling, and storage. The AC sheets are manufactured by mixing chrysotile fibers and cement in a wet process. In the process, the mixture is weighted, and water is added to the mixture for making slurry. The mixture is charged into molds during the steam process. Asbestos cement sheets production requires large numbers of finishing machines such as cutting and drilling equipment to make the end products (Fig. 1.). At the end of the process, AC products are transported by lift truck.

Fig. 1 Cutting process for AC sheet manufacture

Exposure assessment

Forty-five personal air samples were collected from different processes in the plant. The airborne asbestos samples were collected on mixed cellulose ester filter membranes (Millipore type AA; 0.45 um pore size; 25 mm diameter) using an open-face filter holder and a cellulose support pad contained in a three-piece cassette with a 50-mm conductive extension cowl. Sampling was performed at a nominal flow rate of 2 l/min using a battery-powered personal sampling pump (Model Number 224-PCMTX8; SKC UK). The duration of personal sampling for airborne asbestos was 60 min. All samples were collected in the breathing zone and prepared and analyzed according to National Institute for Occupational Safety and Health (NIOSH) method 7400 (NIOSH 1989). In this method, the filter is first treated by acetone vapor to make it transparent and then analyzed by PCM (magnification of ×400–450) using Walton–Bechett graticulte (type G-22). The method measures airborne fibers, defined as particles with a length greater than 5 um, width lower than 3 um, and aspect ratio > 3:1. (Kakooei et al. 2009). Although the method (NIOSH 1989) is relatively fast, it does not distinguish between asbestos and non-asbestos fibers, and it cannot detect fibers thinner than 0.25 μm (Kakooei and Marioryad 2010). Therefore, the fiber type and its chemical composition were also evaluated by SEM specified by the Asbestos International Association (AIA 1984). SEM (model XL30; Philips, Eindhoven, The Netherlands) was used in combination with energy-dispersive X-ray analysis to identify asbestos fibers during analysis of our samples.

Data analysis

Descriptive statistics was conducted for asbestos fiber concentrations using the SPSS software for windows ver.13.5. The mean fiber concentrations are indicated as geometric means. The fiber concentration, C, in f/ml is determined by the following formula:

$$C = \frac{(E) \times (A_C)}{V \times 10^3}$$

Where C is for fibers (f/ml), E fiber density (f/mm^2), A_C effective filter area (in square millimeters), and V air volume sampled (liter).

Table 1 Fiber concentrations (f/ml) for different processes in the Ac sheet manufacture

Process	Number	Fiber concentrations (f/ml)			Number of samples
		GM(GSD)	AM(SD)	Range	Exceeding TLV, N (%)
Feeding of raw materials	7	0.1645 (1.02)	0.1674 (0.03)	0.124–0.211	4 (57.1)
Mixing	7	0.0208 (1.02)	0.0211 (0.01)	0.016–0.026	0
Molding of sheet	8	0.0464 (1.17)	0.0545 (0.02)	0.012–0.088	0
Unloading car	7	0.0481 (1.01)	0.0481 (0.01)	0.043–0.053	0
Cutting & drilling	9	0.0776 (1.23)	0.0775 (0.06)	0.035–0.243	3 (33.3)
Sheet storage	7	0.0264 (1.11)	0.0264 (0.01)	0.014–0.051	0
Total	45	0.0522 (1.36)	0.0708 (0.05)	0.012–0.243	7 (15.5)

N number of samples; *GM* geometric mean; *GSD* geometric standard deviation; *Am* arithmetic mean; *SD* standard deviation

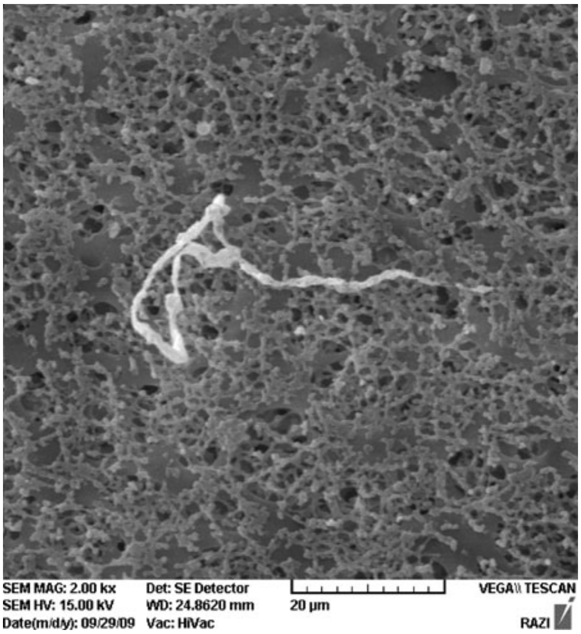


Fig. 2 SEM image of chrysotile in dust. Magnification ×2,000

The time weighted average airborne asbestos concentrations were calculated from consecutive 60-min samples collected from the worker using the following equation.

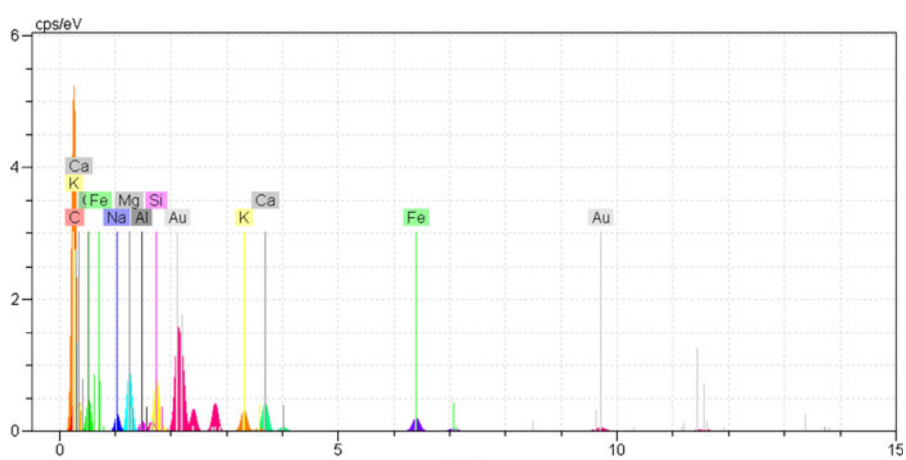
$$\mathrm{TWA} = \frac{(C_1 \times T_1) + (C_2 \times T_2) + \cdots + (C_n \times T_n)}{T_1 \times T_2 + \cdots + T_n}$$

Where C_1 is the average airborne concentration (f/ml) for the breathing zone for each of the sampling segments and t_1 is the duration of the task.

Results and discussion

Iran uses about 3–4% of world's chrysotile asbestos produced. Geometric mean values of airborne asbestos samples are presented in Table 1. These results show the highest geometric mean concentration of asbestos (0.16 ± 1.02 PCM f/ml) in the feeding of raw materials. Geometric mean was significantly higher in the feeding process as compared to the other processes ($p < 0.05$) in the plant. Table 1 also shows that the geometric mean value for mixing operation was lower (0.02 ± 1.02 PCM f/ml) than other operations. Geometric mean of airborne asbestos in the personal samples was 0.05 f/ml, which is below the level of 0.1 recommended for asbestos exposure by the ACGIH (2008). Congruent with previous studies, this study confirms that AC sheet (CRS) manufacture workers have a lower occupational exposure in the wet process (Ansari et al. 2007; Sudhir and William 2010; Phanprasit et al. 2009). In contrast, these authors reported that mean asbestos concentrations in dry processes such as automobile brake and clutch manufacture were 0.63–0.87 PCM f/ml, which were higher than that observed in this study (Kakooei et al. 2007;

Fig. 3 EDS spectrum of the airborne chrysotile. Chrysotile contains Si and Mg



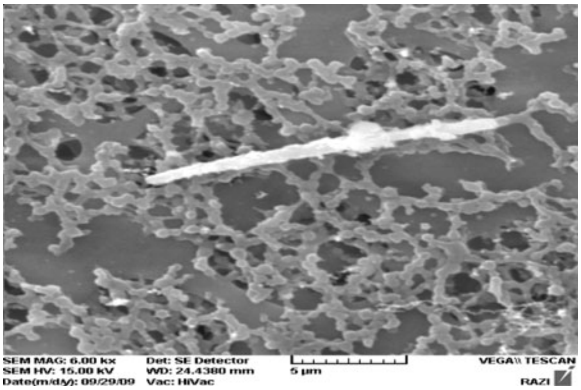
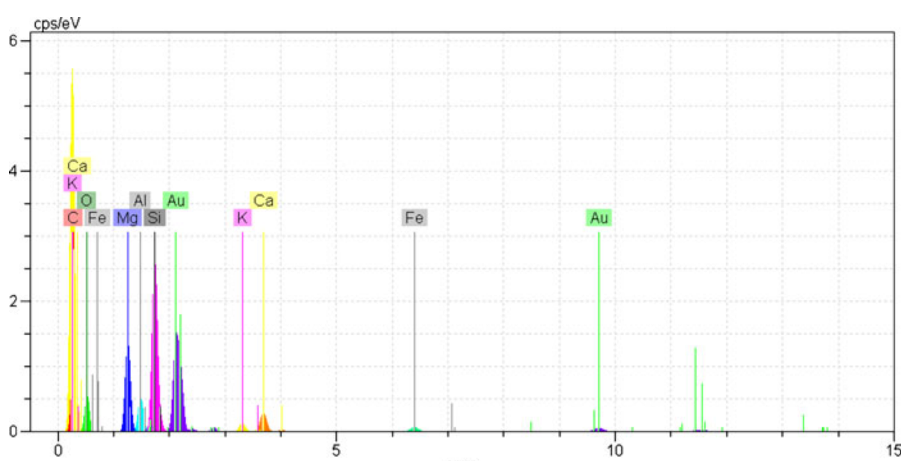


Fig. 4 SEM image of amphibole (Tremolite) in dust. Magnification ×6,000

Kakooei and Marioryad 2010). The results also have highlighted that 15.5% of the samples were found to be above the TLV. Fiber type and size were evaluated for the samples collected during the AC sheet manufacturing processes. The SEM image, Figs. 2 and 4 were obtained by conventional instrument with a gold evaporation coating and show airborne chrysotile and tremolite fibers in the workplace environment. The chemical composition of the fibers was analyzed using energy-dispersive spectrometry (EDS) (Figs. 3 and 5). Chrysotile asbestos usually is rich in Mg but has a low content of iron (Fe). When all data are considered in the EDS spectrum, the results indicate that fibrous particles in the airborne dust consisted of chrysotile (55.89%) and amphibole (44.11%). The length and diameter of an asbestos fiber appears to be one of the most important variables of its toxicity (Kakooei and Marioryad 2010; Tossavainen et al. 2001). As we can see in Figs. 2 and 4, the diameter of chrysotile fibers (0.2–0.5 um) was mostly smaller than that of amphiboles fibers (0.7–1.0 μm). As mentioned above, chrysotile asbestos was used to manufacture AC sheet products in the factory, but it has been known that the imported chrysotile also contain amphiboles. It is interesting to note that tremolite and actinolite asbestos are present in or around some of chrysotile mines (Gunter et al. 2007; Yano et al. 2001; Weir and Meraz 2001). However, levels of amphibole asbestos in commercial chrysotile have not always been reported (Kakooei and Marioryad 2010). Moreover, analyses of the asbestos in dusts indicated that the rate of amphibole contamination is substantially higher than reported in other studies (Stayner et al. 1996; Yano et al. 2001; Gunter et al. 2007). As shown in Figs. 2, 3, 4, and 5, the SEM analysis and EDS spectrum of air samples from various processes of the factory showed images and chemical content compatible with the chrysotile and tremolite series with some evidence of Mg, Si, Fe , and calcium (Ca) content. It should be noted that tremolite asbestos contains Ca and Mg, whereas in actinolite, Mg is replaced by Fe. Chrysotile asbestos fibers are usually curved (Fig. 2.), in contrast to a straight morphometry (Fig. 4.) of the amphibole (tremolite). As noted above, the airborne asbestos

Fig. 5 EDS spectrum of the airborne tremolite. Tremolite contains Ca and Mg



contains Mg and Si and the Mg/Si ratio is 1.4, while tremolite and actinolite contains Ca and the Mg/Si ratio is about 0.2. As noted earlier, the AC sheet industries import all their chrysotile asbestos from other countries and that the high levels of airborne amphibole asbestos is largely attributed to contamination of chrysotile asbestos.

Conclusion and recommendations

In conclusion, the geometric mean values of airborne asbestos in 84.5% of the processes were found to be below the TLV. It can be also concluded that the consumption of imported chrysotile asbestos ore that contains tremolite and actinolite asbestos are responsible for the high airborne amphibole asbestos levels in AC sheet plant environments. Thus, more research is needed to improve the characterization of occupational exposures by fiber size and concentration in a variety of industries. Meanwhile, banning the use of asbestos and implementation of technology to produce high-quality non-asbestos AC products are strongly recommended.

References

ACGIH American Conference of Governmental Industrial Hygienists (2008). *Threshold limit values for chemical substances and physical agents and biological indices*. Cincinnati: ACGIH.

AIA Asbestos International Association (1984). *Method for the determination of airborne asbestos fibers and other inorganic fibers by scanning electron microscopy*. London: AIA Health and Safety, Publ RTM no 2. AIA.

Ansari, F. A., Bihari, V., Rastogi, S. K., Ashquin, M., & Ahmad, I. (2007). Environmental health survey in asbestos cement sheets manufacturing industry. *Indian Journal of Occupational and Environmental Medicine, 11*(1), 15–20.

Dement, J. M., & Wallingford, K. M. (1990). Comparison of phase contrast and electron microscopic methods for evaluation of occupational asbestos exposures. *Applied Occupational Hygiene, 5*, 242–247.

Goldberg, M., Banaei, A., Goldberg, S., Auvert, B., Luce, D., & Gueguen, A. (2000). Past occupational exposure to asbestos among men in France. *Scand Journal Work Environmental Health, 26*, 52–61.

Gunter, M. E., Sanchez, M. S., & Williams, T. J. (2007). Characterization of chrysotile samples for the presence of amphiboles: The Carey Canadian Deposit, Southeastern Quebec, Canada. *Canadian Mineralogist, 42*(2), 263–280.

Kakooei, H., & Marioryad, H. (2010). Evaluation of exposure to the airborne asbestos in an automobile brake and clutch manufacturing industry in Iran. *Regular Toxicology and Pharmacology, 2*, 234–245.

Kakooei, H., Sameti, M., & Kakooei, A. A. (2007). Asbestos exposure during routine brake lining manufacture. *Industrial health, 45*, 787–792.

Kakooei, H., Yunesian, M., Marioryad, H., & Azam, K. (2009). Assessment of airborne asbestos fiber concentrations in urban area of Tehran, Iran. *Air Qualifications Atmospheric Health, 2*, 39–45.

Lippmann, M. (1988). Asbestos exposure indices. *Environmental Research, 45*, 86–106.

McDonald, A. D., Case, B. W., Churg, A., Dufresne, A., Gibbs, G. W., Sebastien, P., et al. (1997). Mesothelioma in Quebec chrysotile miners and millers: Epidemiology and etiology. *Annals Occupational Hygiene, 41*, 407–719.

Nicholson, W., Landrigan, P. J. (1994). Asbestos: A status report. *Current Issues Public Health, 2*, 118–123.

NIOSH National Institute for Occupational Safety and Health (1989). *Method 7400: Fibers. In: NIOSH manual of analytical methods*, (3rd edn). Cincinnati: U.S. Department of Health, Education and Welfare.

Phanprasit, W., Sujirarat, D., Chaikittiporn, C. (2009). Health risk among asbestos cement sheet manufacturing workers in Thailand. *Journal of the Medical Association of Thailand, 7*(S), 115–120.

Stayner, L., Dankovic, D. A., Lemen, R. A. (1996). Occupational exposure to chrysotile asbestos and cancer risk: a review of the amphibole hypothesis. *American Journal Public Health, 86*(2), 179–186

Sudhir, K. D., & William, S. B. (2010). Occupational asbestos exposure and predictable asbestos-related diseases in India. *American Journal of Industrial Medicine, 48*(2), 137–143.

Sullivan, J. B., & Krieger, G. R. (2001). *Clinical environmental health and toxic exposures*. Baltimore: Lippincott Williams &Wilkins.

Tossavainen, A., Kotilainen, M., Takahashi, K., Pan, G. & Vanhala, E. (2001). Amphibole fibers in Chinese chrysotile asbestos. *Annals Occupational Hygiene, 45*(2), 145–152.

Weir, F. W., Meraz, L. B. (2001). Morphological characteristics of asbestos fibers released during grinding and drilling of friction products. *Applied Occupational Environmental Hygiene, 16*, 1147–1149.

Yano, E., Wang, Z. M., Wang, X. R., Wang, M. Z., & Lan, Y. J. (2001). Cancer mortality among workers exposed to amphibole-free chrysotile asbestos. *American Journal Epidemiology, 145*, 538–543.