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Assessment of airborne asbestos exposure at an asbestos cement sheet and pipe factory in Iran

Hossein Marioryad [a,b], Hossein Kakooei [a,*], Seyed Jamaleddin Shahtaheri [a], Masud Yunesian [c], Kamal Azam [d]

[a] Department of Occupational Health, School of Public Health, Tehran University of Medical Sciences, Tehran, Iran
[b] Msc of Occupational Health, Department of Environmental Health, Faculty of Health, Yasuj University of Medical Sciences, Yasuj, Iran
[c] Department of Environmental Health, Tehran University of Medical Sciences, Tehran, Iran
[d] Department of Statistics and Epidemiology, Tehran University of Medical Sciences, Tehran, Iran

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ABSTRACT

Iran imports nearly 55,000 metric tons of asbestos per year, and asbestos cement (AC) plants contribute nearly 94% of the total national usage. In the present study, asbestos fiber concentrations during AC sheet and pipe manufacturing were measured by phase-contrast microscopy (PCM) and polarized light microscopy (PLM) in 98 personal air samples. The fiber type and its chemical composition were also evaluated by scanning electron microscopy (SEM) and energy-dispersive X-ray analysis (EDX). Personal monitoring of fiber levels indicated a range from 0.02 to 0.55 PCM f/ml (0.02–0.69 PLM f/ml). The AC workers' geometric mean asbestos exposure was 0.09 PCM f/ml (0.11 PLM f/ml), with arithmetic mean of 0.13 PCM f/ml (0.16 PLM f/ml). The observed fiber concentrations in many processes were higher than the threshold limit value (TLV) proposed by the American Conference of Governmental Industrial Hygienists (ACGIH), which is 0.1 f/ml. Based on these findings, the PLM values were approximately 25% higher than PCM values. The SEM data demonstrate that fibrous particles contained chrysotile. The thinnest fiber recognized by SEM had a diameter of 0.2 μm. Mean exposure exceeded the TLV for asbestos in pipe molding and finishing (100%) as well as sheet molding and finishing (45.5–83.3%). In conclusion exposure control may be needed to be in compliance with the ACGIH TLV and other guidance levels. Also, with regard to PCM limitations for airborne fiber analysis, the use of microscopic methods other than PCM can be used to improve the techniques used presently.

1. Introduction

Evaluation of occupational exposure to air contaminants has been a key element of safety and health programs in the workplace (Melville and Lippmann, 2001). Because the hazard to human health caused by exposure to airborne inorganic fibers, such as asbestos, is definitively established, measuring inhalation exposure of workers to fibrous particles has been a constant concern of occupational hygienists for many years (Kauffer and Vincent, 2007; Belluso et al., 2006; Verma and Clark, 1995; Richardson, 2009). Asbestos and asbestiform fibers are naturally occurring fibrous silicates with several important commercial uses. They can be classified as amphiboles (including amosite, crocidolite, anthophyllite, actinolite and tremolite) or chrysotile (Bourdes et al., 2000). Asbestos has been used extensively in industrial materials, such as AC sheets, AC pipes, automobile brakes and clutches, vinyl asbestos floors, ventilation ducts, and thermal and electrical insulation materials (Kakooei et al., 2007, 2009). The crystalline silicate mineral breaks into microscopic fibers that become airborne. Particulate matter with a length ⩾5 μm and aspect ratio ⩾3:1 belongs to the fibrous group (Wylie et al., 1993).

Presently, some countries have stopped using all types of asbestos (Muhle and Pott, 2000; Richardson, 2009). However, widespread manufacturing and consumption of asbestos products continues in developing countries (Trivedi et al., 2004; Kakooei and Marioryad, 2010). The ACGIH, OSHA and NIOSH elaborated a time-weighted threshold limit value (TLV-TWA), permissible exposure limit (PEL), and recommended exposure limit (REL), all of which are 0.1 f/ml (ACGIH, 2010).

Due to the high health risk experienced by those working with amphiboles, chrysotile has been substituted for asbestos sheet and pipe when possible (Kumagai and Kurumatani, 2009). Currently, over 95% of asbestos production involves the use of white asbestos (chrysotile). Notably, imported raw chrysotile has been found to contain impurities, which have been identified as other types of asbestos (Kakooei and Marioryad, 2010; Panahi et al., 2010).

A total of 11 AC sheet and pipe manufacturing plants are founded in Iran; approximately 4000 workers are exposed to

* Corresponding author. Address: Department of Occupational Health, School of Public Health, Tehran University of Medical Sciences, Tehran 9821, Iran. Fax: +98 21 88951390.
E-mail addresses: hkakooei@sina.tums.ac.ir, kakooei@gmail.com (H. Kakooei).

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asbestos fibers (Panahi et al., 2010). Approximately 55,000 metric tons per year have been imported in the last 10 years, and more than 90% of that is being used in AC manufacturing. The use of asbestos in Iran has not declined, and the current per capita consumption level is 0.8 kg/capita/year (Kakooei and Marioryad, 2010; Panahi et al., 2010).

Three factors including concentration, dimension and type of fibers are important in airborne fibers assessment (Harper and Bartolucci, 2003). There are more than 30 different standard methods for the analysis of asbestos (Dodson et al., 2008). Numerous optical and electron microscopy methods have been developed to quantify asbestos fibers in air (HEI, 1991; Vallero et al., 2009). Phase contrast microscopy methods have revealed a positive correlation between the incidence of asbestos-related diseases and the level of exposure to airborne asbestos (Wylie and Bailey, 1992; Middendorf et al., 2007). Although PCM as a simple and fast method has been used for many years, but its counting scheme only able to determine fibers concentration and to identify fibers type is incapable (NIOSH, 1994; OSHA, 1997; Dodson and Atkinson, 2006). Also, PCM may yield inaccurate chrysotile fiber counts (NIOSH, 1994; OSHA, 1997; Pang, 2000). Therefore, to overcome these limitations, other microscopic methods can be used. In several study, transmission and scanning electron microscopy methods have been used to determine the concentration, size and type of asbestos fibers (HEI, 1991; Santee and Lott, 2003; Eypert-Blasion et al., 2009; Panahi et al., 2010). The objectives of this study were to determine occupational exposure to airborne asbestos during AC sheet and pipe manufacturing by PCM and PLM in a developing country. We also sought to characterize asbestos subtypes, based on evaluations of raw materials and airborne asbestos samples.

2. Materials and methods

2.1. Protocol

This study was performed in an AC sheet and pipe manufacturing plant in Tehran (Iran) in 2010. The factory has produced AC sheet and pipe since the 1960s; its production is estimated at >100,000 metric tons annually. The factory currently employs 350 workers with a mean age of 40 years and mean employment length of 15 years. The raw materials used in the factory are chrysotile (14–20%), polypropylene fibers (<1%) and cement (75–80%). A few years ago, this factory was equipped with general and local ventilation. AC sheet and pipe manufacturing are initiated by mixing asbestos fibers and cement in a wet process. Then, water is added to the mixture, yielding a slurry mixture. The mixture is poured into molds during the steam process, and AC sheets and pipes are produced. Finally, production requires multiple finishing processes such as cutting, drilling and grinding.

2.2. Sampling and analysis

During the study period, 98 personal air samples were collected from different parts of the plant engaged in different aspects of production. The airborne asbestos samples were collected on mixed cellulose ester (MCE) filter membranes with support pads, using an open-face filter holder with a 50-mm conductive extension cowl. Sampling was performed at a flow rate of 2 l/min using a personal sampling pump (Model Number 224-PCMTX8; SKC-UK). The duration of personal sampling for airborne asbestos was 60–240 min. One-half of each filter examined was mounted on a glass slide (75 × 25 mm) and prepared and analyzed according to NIOSH method 7400. Fibers were counted by PCM and PLM with plane polarized light separately at 400× magnification using a Walton-Beckett graticule (type G-22). The method measures airborne fibers with a length ⩾5 μm and aspect ratio ⩾3:1. As mentioned in the literature, asbestos is an anisotropic material; therefore, colored images of asbestos fibers under PLM should be used to quantify airborne asbestos. Fiber type and chemical composition of breathing zone samples were evaluated by SEM as specified by the International Organization for Standardization (ISO, 2002). SEM (model WEGA//TESCAN, Czech Republic) and energy-dispersive X-ray analysis (EDXA) was used to identify fiber type during the analysis. Raw materials (asbestos and polypropylene) were analyzed by SEM.

2.3. Data analysis

Descriptive statistics were used for PCM and PLM measurements of the asbestos fiber concentrations using SPSS software for Windows. The mean fiber concentrations are presented as arithmetic and geometric means. The fiber concentrations were determined by the following formula:

$$C = \frac{\left(\frac{\frac{F}{n_f} - \frac{B}{n_b}}{A_f}\right) \times (A_c)}{V \times 10^3}$$

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

Process	N	Fiber concentrations (f/ml)		Number of samples Exceeding TLV N (%)
		PLM Results -AM(SD) -GM(GSD) -Range	PCM Results -AM(SD) ***-GM(GSD)*** -Range	
Storage (raw materials and productions)	7	0.069(0.011) 0.068(1.18) 0.05–0.08	0.056(0.01) ***0.055(1.2)*** 0.04–0.07	0(0)
Feeding of raw materials (milling and mixing)	8	0.161(0.047) 0.155(1.34) 0.1–0.25	0.131(0.027) ***0.129(1.24)*** 0.09–0.1 7	7(87.5)
Sheet molding (hacheck, perdorit)	11	0.101(0.037) 0.094(1.5) 0.04–0.17	0.085(0.025) ***0.081(1.39)*** 0.04–0.12	5(45.5)
Pipe molding	12	0.154(0.031) 0.151(1.22) 0.11–0.21	0.125(0.021) ***0.124(1.17)*** 0.1–0.17	12(100)
Sheet finishing	12	0.208(0.083) 0.191(1.54) 0.09–0.37	0.168(0.069) ***0.155(1.53)*** 0.08–0.3	10(83.3)
Pipe finishing	13	0.269(0.079) 0.259(1.34) 0.17–0.41	0.223(0.065) ***0.215(1.34)*** 0.14–0.34	13(100)
Recycling (residual mill)	7	0.543(0.076) 0.539(1.14) 0.46–0.69	0.453(0.06) ***0.45(1.14)*** 0.39–0.55	7(100)
Laboratory (physics lab, chemistry lab)	8	0.05(0.019) 0.047(1.48) 0.03–0.08	0.041(0.014) ***0.039(1.45)*** 0.02–0.06	0(0)
Administration (health care clinic, office)	12	0.048(0.017) 0.045(1.46) 0.02–0.08	0.043(0.015) ***0.040(1.49)*** 0.02–0.06	0(0)
Others (kitchen, dining, laundry)	8	0.051(0.018) 0.049(1.38) 0.03–0.09	0.040(0.011) ***0.039(1.29)*** 0.03–0.06	0(0)
Total	98	0.162(0.139) 0.118(2.26) 0.02–0.69	0.134(0.115) ***0.098(2.23)*** 0.02–0.55	49(50)

N, number of samples; PLM, polarized light microscopy; PCM, phase contrast microscopy; AM, arithmetic mean; GM, geometric mean; GSD, geometric standard deviation; TLV, threshold limit value.

where C is the concentration offibers (f/ml), A_c the effective filter area (approx. 385 mm^2), $\frac{F}{n_f}$ the average fiber count per graticule field, $\frac{B}{n_b}$ the mean field blank count per graticule field, A_f graticule field area (approx. 0.00785 mm^2) and V is the air volume sampled (liter).

For identification of fiber type, the elemental composition of raw materials and airborne fibers were identified by SEM-EDXA and compared with standard spectrums (BS ISO 14966, 2002).

3. Results

3.1. Asbestos fiber concentrations

The geometric (GM) and arithmetic mean (AM) values of airborne asbestos in the personal samples are presented in Table 1. The confidence interval of different situations of exposure also is shown in Fig. 1. As summarized in Table 1, the highest and lowest geometric mean concentrations of asbestos (0.450 ± 1.14 PCM f/ml and 0.039 ± 1.45 PCM f/ml) were found in connection with the recycling process (residual mill) and laboratory, respectively. As the results show, all of the workers involved in pipe molding and finishing, and residual mill processes were exposed to airborne asbestos higher than the TLV proposed by ACGIH, which is 0.1 f/ml. The results show that 50% of the personal samples exceeded the TLV. Table 1 also shows that the AM and GM values for PLM counts were higher than those obtained by PCM ($p < 0.05$).

3.2. Fiber type and morphology

Fiber size and morphology among samples collected during the AC sheet and pipe manufacturing process were analyzed. Figs. 3 and 4 present images obtained using conventional SEM with a gold evaporation coating. The images reveal chrysotile in the raw asbestos and workplace environment. The chemical composition of the fibers was analyzed using energy-dispersive spectrometry (EDS) analysis (Figs. 2–4). Fig. 2 shows the SEM image and EDS spectrum of the raw polypropylene, which was used in the factory. The SEM image and EDS spectrum collected from the airborne and raw material chrysotile fibers are shown in Figs. 3 and 4. These spectrums show the chemical analysis and magnesium to silica (Mg/Si) ratios of 1.22 and 1.40, respectively. Fig. 5 shows the SEM fiber diameter detection limit, according to BS ISO 14966, 2002, at 2000× magnification.

4. Discussion

AC sheet and pipe manufacturing involves the use of chrysotile asbestos (Kakooei et al., 2007; Kakooei and Marioryad, 2010). This study confirms that AC sheet factory workers experience the highest occupational exposure to airborne asbestos in the sheet-finishing and recycling processes (Panahi et al., 2010). Panahi reported that GM asbestos concentrations during the wet process of AC sheet manufacture averaged 0.05 PCM f/ml, which is lower than the figures we found in our study. In general, in the current study, the levels of airborne asbestos concentrations (GM) estimated in the workplace environment (0.09 PCM f/ml) differ from those reported by previous studies (Kakooei et al., 2007; Kakooei and Marioryad, 2010). Similar to previous studies, this study also confirms that the wet process involves reduced occupational exposure to airborne asbestos (Panahi et al., 2010).The personal PLM results were higher than the PCM results for all air samples. Notably, fiber counting (especially chrysotile fiber counting) with the PCM method may underestimate ambient levels of asbestos (Pang, 2000; Kohyama and Kurimori, 1996). With regard to the many issues involved in the optical detection and recognition of fibers, the degree of contrast between the fibers and the background as well as the position of fibers in several different focal planes may allow some fibers to be missed when quantified using PCM (Harper and Bartolucci, 2003). When compared with the verified fiber counts, it is apparent that the number of chrysotile fibers was underestimated by 25%. Counting errors were 59.2% for every 100 fibers reported (Pang, 2000). Although the PLM resolution is not greater than that of PCM, the major source of chrysotile counting errors is the oversight of fibers: chrysotile fibers under plane-polarized light have

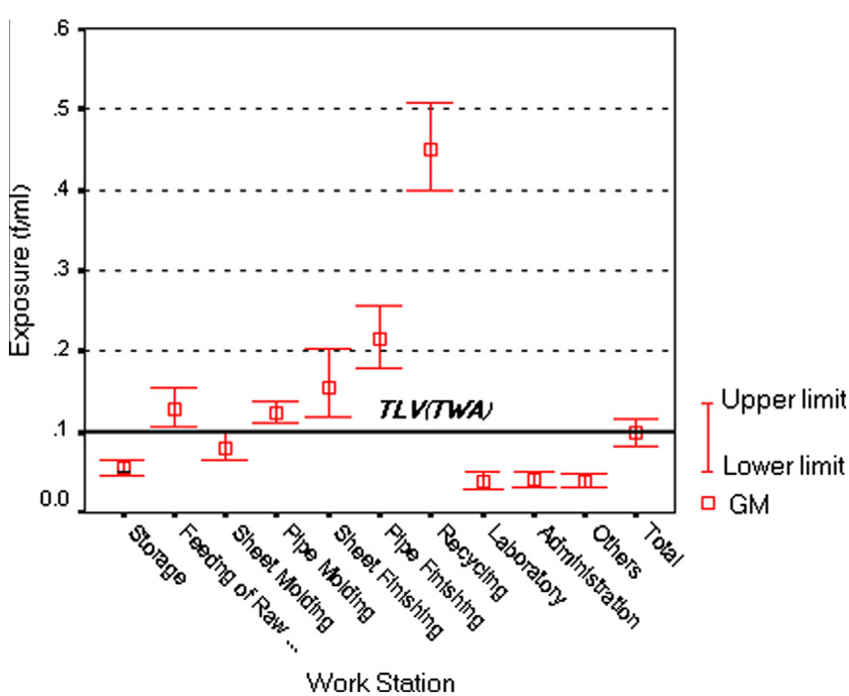

Fig. 1. Confidence interval of airborne fiber concentration (f/ml) in different workstations of an AC sheet and pipe manufacturing factory, as determined by PCM.

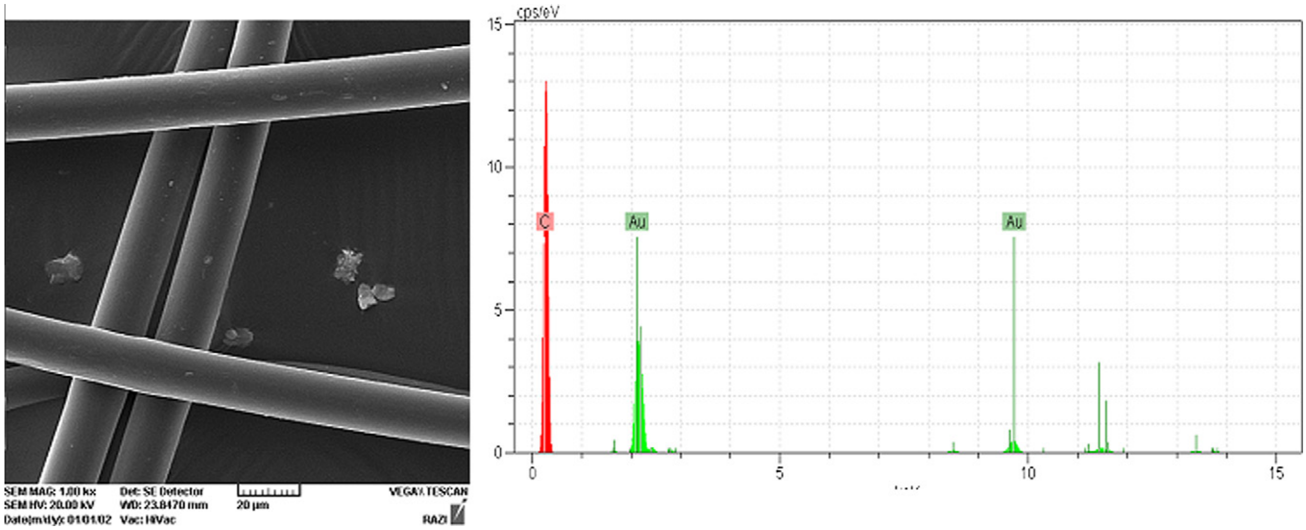

Fig. 2. SEM image and EDS spectrum of polypropylene fibers (raw materials). Magnification, 1000×.

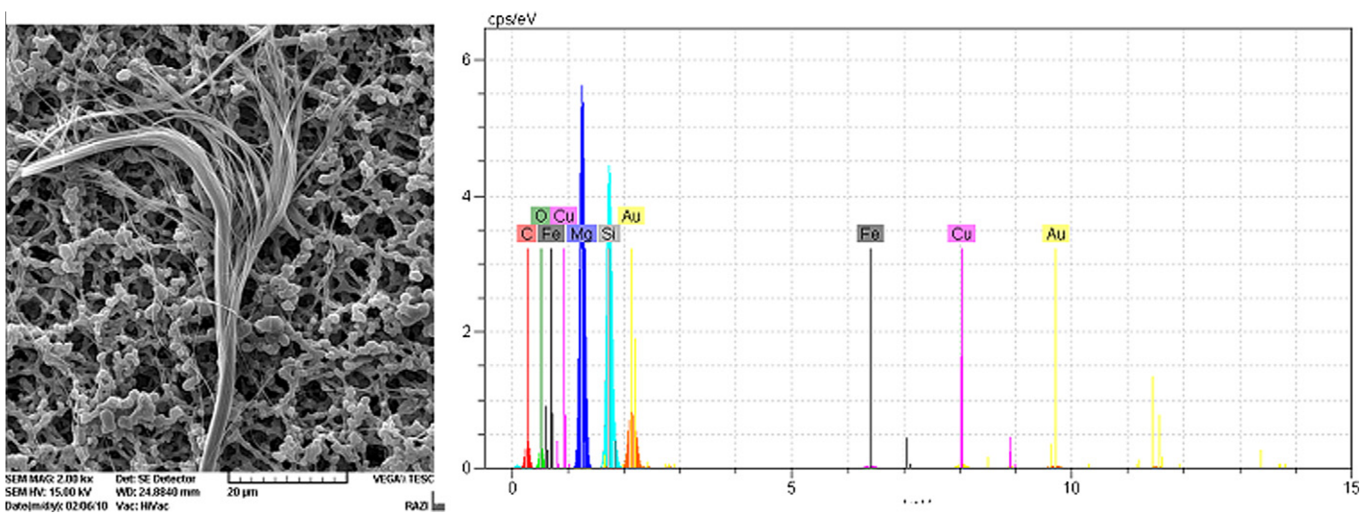

Fig. 3. SEM image and EDS spectrum of chrysotile (raw materials). Magnification, 2000×.

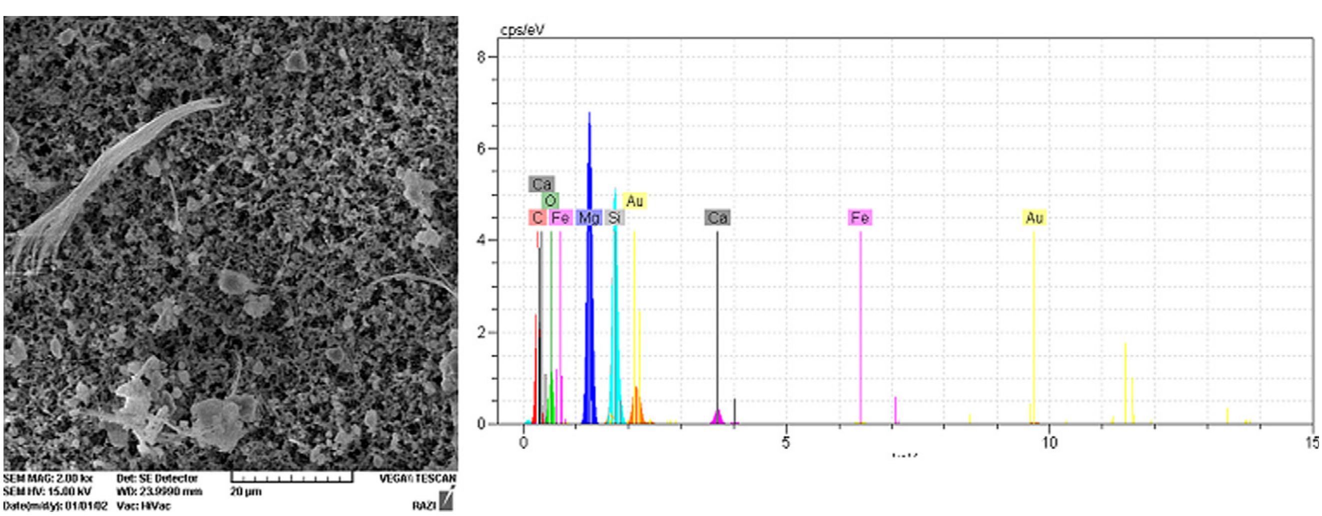

Fig. 4. SEM image and EDS spectrum of airborne chrysotile. Magnification, 2000×.

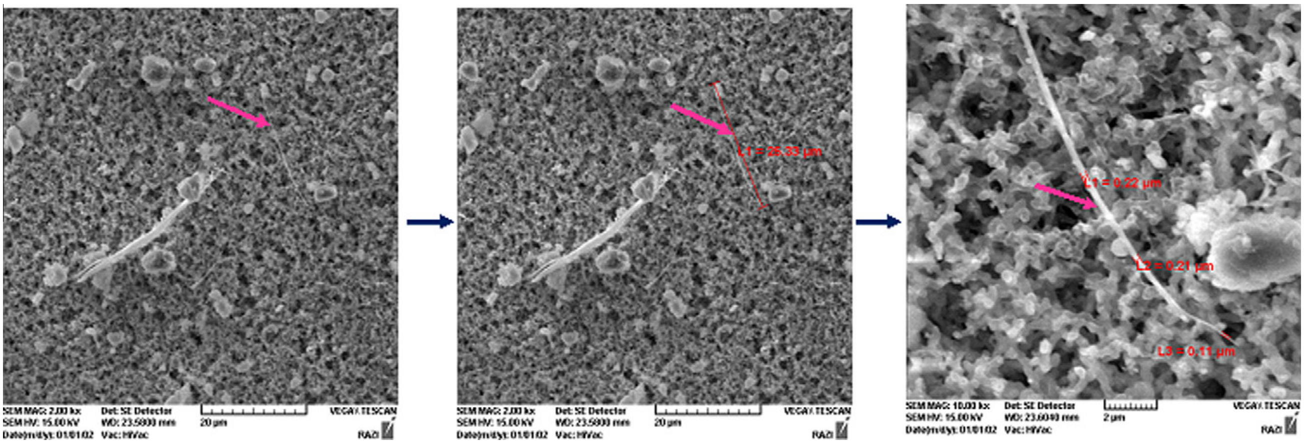

Fig. 5. Determination of fiber size by SEM. Magnification, 2000× & 10000×.

different colors. Blue and gold-brown colors in various directions are observed more clearly in different focal planes, and the probability of missing fibers is reduced.

The results of raw material analysis by SEM are presented in Figs. 2 and 3. The SEM images and spectrums of polypropylene and asbestos were used for comparison with airborne fibers. Chrysotile asbestos is usually rich in Mg and Si but has low iron content (ISO 14966, 2002). Fiber morphology and EDX spectrum showed that all samples examined contained only chrysotile asbestos (Fig. 4). No polypropylene fibers were observed in the samples, which is attributed to the very low proportion of polypropylene used in AC sheet and pipe manufacturing (Fig. 1). Notably, tremolite and actinolite asbestos are present in or around certain chrysotile mines (Yano et al., 2001; Weir and Meraz, 2001). Some studies have shown that the imported chrysotile contained amphibole fibers (Kakooei and Marioryad, 2010; Panahi et al., 2010), but as mentioned above, the chrysotile asbestos used in this factory contained no amphiboles.

In conclusion, because the PCM method has some limitations with regard to airborne fiber analysis, the use of microscopic methods other than PCM can be used to improve the techniques used presently. The results of this study have highlighted that 50% of personal samples studied contained average fiber concentrations that exceeded the REL proposed by the NIOSH (0.1 f/ml). Despite findings of exposures in excess of OSHA and NIOSH recommendations, it is unknown if these exposures have any potential health consequences for exposed workers. Periodic monitoring, full engineering controls and respiratory protection are recommended to be in compliance with OSHA and NIOSH recommendations.

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