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Asbestos-Containing Materials and Airborne Asbestos Levels in Industrial Buildings in Korea

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Abstract: Recently in Korea, the treatment of asbestos-containing materials (ACM) in building has emerged as one of the most important environmental health issues. This study was conducted to identify the distribution and characteristics of ACM and airborne asbestos concentrations in industrial buildings in Korea. A total of 1285 presumed asbestos-containing material (PACM) samples were collected from 80 workplaces across the nation, and 40% of the PACMs contained more than 1% of asbestos. Overall, 94% of the surveyed workplaces contained ACM. The distribution of ACM did not show a significant difference by region, employment size, or industry. The total ACM area in the buildings surveyed was 436,710 m². Ceiling tile ACM accounted for 61% (267,093 m²) of the total ACM area, followed by roof ACM (32%), surfacing ACM (6.1%), and thermal system insulation (TSI). In terms of asbestos type, 98% of total ACM was chrysotile, while crocidolite was not detected. A comparison of building material types showed that the material with the highest priority for regular management is ceiling tile, followed by roof, TSI, and surfacing material. The average airborne concentration of asbestos sampled without disturbing in-place ACM was 0.0028 fibers/cc by PCM, with all measurements below the standard of recommendation for indoor air quality in Korea (0.01 fibers/cc).

Key words: asbestos, asbestos-containing material, ceiling tile, management.

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Introduction

Asbestos is the name given to a group of six different fibrous minerals (amosite, chrysotile, crocidolite, tremolite, actinolite, and anthophyllite) that occur naturally in the environment [1]. Asbestos fibers do not dissolve in water or evaporate and are resistant to heat, fire, chemical and biological degradation. Because of these properties, asbestos has been used in a wide range of manufactured goods, including roofing shingles, slate, ceiling and floor tiles, coatings, and friction materials such as brake and transmission parts.

Exposure to asbestos can be harmful to human health if asbestos fibers are inhaled into the lungs after being released into the air when asbestos is disturbed or in poor condition. Numerous epidemiological studies have shown that exposure to asbestos may cause asbestosis, lung cancer and mesothelioma of the pleura or the peritoneum [2–7]. Asbestos has been declared a proven human carcinogen by the U.S. Environmental Protection Agency (EPA) and by the International Agency for Research on Cancer (IARC) [8, 9]. The World Health Organization (WHO) estimates that today 125 million people are being occupationally exposed to asbestos and that such exposures lead to 90,000 deaths every year [10]. The first cases of asbestosis in Korea were found in 1993 with the first national survey of asbestos manufacturing facilities [11]. Malignant mesotheliomas have been diagnosed since the 1970s, however, it was only in 1993 when the first case of compensable malignant mesothelioma was diagnosed in Korea. There were 334 deaths attributed to malignant mesothelioma between 1996 and 2006 [12].

Most developed countries have banned the use of asbestos products [13–15]. While use of asbestos materials in developed nations has been decreasing because of the harmful health effects of asbestos, use of those in developing countries is increasing [16]. In 2003, Asian countries accounted for nearly 50% of global asbestos consumption [17].

In Korea, asbestos was first recorded as having been mined in the mid-1930s. Asbestos mining stopped completely in the mid-1980s because domestic production could not compete with cheap imports. All asbestos used in Korea was imported since that time [18]. The amount of asbestos consumption surged with rapid economic growth in the 1960s, as a result of the Economic Development Plan, which pushed the consumption to its record high of 100,866 tons in 1992 [19]. In 1994, Korea ranked fifth worldwide in chrysotile consumption (85,000 tons) [20].

Korea's Occupational Safety and Health Act in 1997 prohibited the use of crocidolite and amosite [21]. Since 2003, building contractors, prior to starting demolition or renovation of buildings with asbestos-containing materials (ACMs), are required to get a permit from the Labor Minister [22]. In July 2007, five government agencies (Ministries of Labor, Environment, Education, Construction and Transportation, and National Defense) announced 'The Comprehensive Asbestos Management Plan'. It included the prohibition of the use of all

kinds of asbestos until 2009, as well as the drawing of an asbestos map for each building from 2010 [23]. As of now, those engaged in the demolition or evacuation of buildings are required to check whether asbestos was used in the building, and in case ACM was used, the approval of the Labor Minister is to be pursued. However, there was no nationwide survey on the distribution of ACM in buildings until 2006.

This study aims to identify the distribution of ACM in industrial buildings across the nation and evaluate the background level of airborne asbestos in various conditions in Korea.

Methods

Site selection

The target sites were derived from a computerized list of the Employment Insurance in Korea. A total of 80 workplaces were chosen and surveyed in 2006. These places were selected to represent diverse industrial settings in Korea, based on the consideration of region (Seoul/Incheon, Gyeonggi, Gangwon/Chungchung, Jeolla, Gyeongsang), the payroll (< 50 , between 50 and 500, > 500), and years of establishment of the workplace (< 1970 , in the 1970s, the 1980s, the 1990s and the 2000s). All large buildings in the target workplaces were covered, while warehouses or temporary buildings were excluded as workers do not routinely stay in these buildings.

Homogeneous sample groups inspected

Homogeneous sample groups (HSGs) were defined as materials that were uniform in color, texture, and appearance and were installed at one time [24]. HSGs in buildings were placed in one of four categories:

1. ceiling materials, such as ceiling board or tile, excluding concrete
2. roof materials, such as slate
3. surfacing materials sprayed or troweled onto structural members, such as beams, columns, decking for fire protection, or on ceilings and sometimes walls or floors, for fire-proofing, acoustical, or decorative purposes
4. thermal system insulation (TSI) applied to steam and hot and cold water systems and heating, ventilating and air conditioning (HVAC) systems to prevent heat transfer and water condensation

During field surveys, ownership of the workplace, construction year for the sample, area of distribution, physical characteristics (friability), and damage severity were also investigated.

In this study, the definition of friability was based on the U.S. EPA's National Emission Standards for Hazardous Air Pollutants (NESHAP). Friable asbestos material means any material containing more than 1% asbestos as determined using polarized light microscopy (PLM), that, when dry, can be crumbled, pulverized, or reduced to powder by hand pressure [25].

If suspect materials were damaged in 10% or more of their surface, they were rated as being in poor condition. If less than 10% of the surface was damaged it was rated fair, and good condition materials had little or no visible damage or deterioration.

Bulk sampling and analysis

Bulk sampling and analysis was conducted according to the US Asbestos Hazard Emergency Response Act (AHERA) [26].

Although the AHERA recommends increasing the number of samples from homogeneous materials correspondingly with the area of distribution, three samples were taken for one HSG in this study irrespective of the distribution area, due to cost and time limits. During the building inspection, bulk samples were collected from exposed or accessible presumed asbestos-containing materials (PACMs), and ceiling tiles, roof materials, and TSI were analyzed for asbestos. Samples were sent for analysis to the US-based laboratory and Korea-based laboratory that are being quality controlled under the National Institute for Occupational Safety and Health (NIOSH) Proficiency Analytical Testing (PAT) program and the US National Voluntary Laboratory Accreditation Program (NVLAP), a globally-recognized accreditation program.

For the decision of ACM or non-ACM, the NIOSH Manual of Analytical Method (NMAM) 9002 Asbestos (bulk) by PLM [27] was used as the criteria for the type of asbestos (chrysotile, amosite, crocidolite, tremolite, anthophyllite or actinolite). Samples detected with more than 1% for any one of these 6 types by visual estimation were classified as ACM. Analysis of three samples collected from each homogeneous material took a negative approach (positive stop). When asbestos was detected in the first sample, the remaining samples were not analyzed and this homogeneous material was reported as ACM. In case all three samples were found to be negative, the homogeneous material was declared as non-ACM.

Air sampling and analysis

Air sampling was conducted to determine the airborne fiber concentrations in occupied buildings. Sampling was conducted in areas where ACM was present in four different conditions by friability (friable vs non-friable) and damage severity (good vs poor or fair).

The air sampling equipment adhered to the requirements of the NIOSH Method 7400 [28] and AHERA [26]. The air samples were taken by drawing air through mixed cellulose ester filters in sampling cassettes with a 5 cm conductive cowl. Normally, sampling pumps were operated at a flow rate of 2-3 l/min. Each sample volume was kept within the range of 700-2,000 l with a target of about 1,500 l. The air samples were analyzed using phase contrast microscopy (PCM) according to the NIOSH Method 7400. All fibers meeting the length and aspect ratio criteria (length > 5 μm and length-to-width ratio > 3 to 1) were counted in more than 100 fields.

Statistical analysis

All of the data was entered into an Excel spreadsheet, and inspected thoroughly for errors by two of the investigators independently before analysis. The chi-square test was used to determine whether there was a significant difference in the distribution of industrial buildings with ACM in various categories such as region, employment size and industry. Descriptive statistics including the arithmetic mean (AM), the geometric mean (GM), the minimum and maximum concentrations (Min, Max), and the geometric standard deviation (GSD) were calculated for airborne asbestos concentrations. The one-way analysis of variance (ANOVA) was used to evaluate the differences in concentrations of asbestos by the conditions of in-place ACM. Statistical analysis was conducted by using SPSS version 12.0.1 for Windows.

Results

ACM distribution by workplace characteristics

The distribution of workplaces with ACM and the results of bulk sampling for building material type are summarized in Table 1 and 2, respectively. A total of 1,285 bulk samples were collected in 80 workplaces and 520 samples were identified as ACM. Overall, 94% of the surveyed workplaces contained ACM (Table 1). As shown in Table 1, the distribution of ACM did not show a significant difference by region (91~100%), employment size (87~100%), or industry (83~100%). The distribution of ceiling tile ACM did not show a large difference by region (63~100%) or employment size (73~94%); nevertheless, a significant

Table 1. Distribution of workplaces with ACM by building material type

Variable	Classification	Workplaces															
		Total	Any ACM			Ceiling tile ACM		Roof ACM		Surfacing ACM		TSI ACM					
		N	N	(%)	χ^2	N	(%)	χ^2	N	(%)	χ^2	N	(%)	χ^2			
Region	Gangwon, Chungbuk, Chungnam	8	8	(100)	2.3	8	(100)	5.0	3	(38)	6.8	5	(63)	12.9*	5	(63)	24.5**
	Gyeonggi	11	10	(91)		9	(82)		3	(27)		4	(36)		8	(73)	
	Gyeongbuk, Gyeongnam	8	8	(100)		6	(75)		3	(38)		5	(63)		7	(88)	
	Jeonbuk, Jeonnam	8	8	(100)		5	(63)		3	(38)		1	(13)		2	(25)	
	Seoul, Incheon	45	41	(91)		39	(87)		5	(11)		8	(18)		8	(18)	
Employees	< 50	15	13	(87)	2.4	11	(73)	2.5	4	(27)	1.5	0	(0)	9.0*	1	(7)	14.1**
	50~500	48	45	(94)		40	(83)		8	(17)		15	(31)		17	(35)	
	> 500	17	17	(100)		16	(94)		5	(29)		8	(47)		12	(71)	
Industry	Manufacturing				5.3			14.7**			2.8			7.9			7.2
	Automotive	11	11	(100)		10	(91)		1	(9)		2	(18)		4	(36)	
	Electric & machinery	15	15	(100)		15	(100)		3	(20)		2	(13)		5	(33)	
	Miscellaneous	23	22	(96)		20	(87)		5	(22)		8	(35)		8	(35)	
	Education	13	12	(92)		12	(92)		2	(15)		2	(15)		2	(15)	
	Social overhead capital & other services	18	15	(83)		10	(56)		6	(33)		9	(50)		11	(61)	
Total		80	75	(94)		67	(84)		17	(21)		23	(29)		30	(38)	

^a: Chi-square value, * $P < 0.05$, ** $P < 0.01$

difference was shown by industry, ranging between 56% and 100% ($P < 0.01$). Roof ACM did not feature a significant difference by region (11~38%), employment size (17~29%) or industry (9~33%). In the case of surfacing ACM, in terms of region, Jeolla province (13%) and Seoul and Incheon (18%) showed a significantly low distribution rate; this type of ACM was not detected at all in workplaces hiring less than 50 workers or in rent buildings. TSI ACM showed a similar profile with surfacing ACM, showing a significant difference by region (18~88%) and employment size (7~71%) ($P < 0.01$).

Characteristics of ACM by building material type

The total ACM area in industrial buildings surveyed was 436,710 m²; Ceiling tile ACM accounted for 61% (267,093 m²) of total ACM area, followed by roof ACM (32%), surfacing ACM (6.1%), and TSI (0.4%) (Table 3). Looking into the characteristics of ACM by construction year, the area distribution of all ACM built before the 1990s showed the highest figure of 50%. The 91% of area of asbestos slate roofs were built before the 1970s and 62% of area of ceiling tiles were built in the 1990s.

The characteristics of ACM by type of asbestos, friability and damage severity are presented in Table 4. The analysis results by asbestos type show that 97.7% of total ACM was

Table 2. Bulk sampling results in industrial buildings by construction year and by material type

Construction year	Total materials			Ceiling tile			Roof materials			Surfacing materials			Thermal system insulation		
	No. HSG ^a	No. ACM ^b	ACM (%) ^c	No. HSG	No. ACM	ACM (%)	No. HSG	No. ACM	ACM (%)	No. HSG	No. ACM	ACM (%)	No. HSG	No. ACM	ACM (%)
< 1970	381	122	(32)	132	39	(30)	72	30	(42)	151	36	(24)	26	17	(65)
1970s	181	91	(50)	77	54	(70)	9	6	(67)	63	13	(21)	32	18	(56)
1980s	262	124	(47)	84	41	(49)	15	6	(40)	67	15	(22)	96	62	(65)
1990s	343	144	(42)	150	77	(51)	18	7	(39)	81	17	(21)	94	43	(46)
2000s	118	39	(33)	55	19	(35)	6	1	(17)	29	3	(10)	28	16	(57)
Total	1285	520	(40)	498	230	(46)	120	50	(42)	391	84	(21)	276	156	(57)

^a:Number of homogeneous sample group, ^b:Number of asbestos-containing material, ^c:Percentage of ACM among HSGs

Table 3. Total area of in-place ACM in industrial buildings surveyed by construction year

Construction year	Area of asbestos-containing materials (m ²)				
	Total	Ceiling tile	Roof materials	Surfacing materials	Thermal system insulation
< 1970	158,193	21,771	128,124	8,213	85
1970s	32,412	22,150	669	9,305	288
1980s	28,577	24,777	1,074	2,125	601
1990s	184,785	166,484	11,490	5,988	823
2000s	32,743	31,911	40	780	12
Total	436,710	267,093	141,397	26,411	1,808

chrysotile. Amosite, tremolite, anthophyllite, and actinolite were detected at less than 7% of total ACM, while no crocidolite was detected.

Friable ACM accounted for 55.6% of total ACM. By building material type, most (86.5%) ceiling tile ACM was friable material; it was 54%, 32.1% and 15.5% for roof, TSI, and surfacing ACM, respectively.

When the damage of ACM was evaluated, 85.8% of total ACM was in fair condition, 14.2% in good condition and none in poor condition. By building material type, most (95.2%) surfacing ACM was partially damaged, followed by roof (94.0%), TSI (93.6%), and ceiling tile (75.2%).

Indoor asbestos concentrations

Table 5 shows the air sampling results for various conditions of in-place ACM. A total of 108 air samples were taken from buildings containing ACM. The results of air sampling for asbestos ranged from 0.0001 to 0.0072 fibers/cc, with a geometric mean of 0.0021 fibers/cc and an arithmetic mean of 0.0028 fibers/cc.

Table 4. Characteristics of ACM by type of asbestos, friability and damage severity

Variable	Classification	All ACM	Ceiling tile ACM	Roof ACM	Surfacing ACM	TSI ACM
		No.(%)	No.(%)	No.(%)	No.(%)	No.(%)
Type of Asbestos	Actinolite	3 (0.6)	1 (0.4)	0 (0.0)	2 (2.4)	0 (0.0)
	Amosite	32 (6.2)	19 (8.3)	5 (10.0)	1 (1.2)	7 (4.5)
	Anthophyllite	1 (0.2)	1 (0.4)	0 (0.0)	0 (0.0)	0 (0.0)
	Chrysotile	508 (97.7)	228 (99.1)	50 (100.0)	80 (95.2)	150 (96.2)
	Crocidolite	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)
	Tremolite	8 (1.5)	2 (0.9)	0 (0.0)	2 (2.4)	4 (2.6)
Friability	Friable	289 (55.6)	199 (86.5)	27 (54.0)	13 (15.5)	50 (32.1)
	Non-friable	231 (44.4)	31 (13.5)	23 (46.0)	71 (84.5)	106 (67.9)
Damage severity	Good	74 (14.2)	57 (24.8)	3 (6.0)	4 (4.8)	10 (6.4)
	Fair	446 (85.8)	173 (75.2)	47 (94.0)	80 (95.2)	146 (93.6)
Total		520 (100.0)	230 (100.0)	50 (100.0)	84 (100.0)	156 (100.0)

Table 5. Summary of indoor asbestos-in-air concentrations for various ACM conditions

ACM condition		No. samples	GM ^a (f/cc)	GSD ^b	AM ^c (f/cc)	SD ^d (f/cc)	Min ^e (f/cc)	Max ^f (f/cc)
Friability	Damage severity							
Friable	Fair	27	0.0017	2.61	0.0024	0.0019	0.0003	0.0072
Friable	Good	27	0.0019	2.41	0.0027	0.0021	0.0003	0.0071
Non-friable	Fair	27	0.0026	2.75	0.0034	0.0018	0.0001	0.0062
Non-friable	Good	27	0.0023	2.10	0.0028	0.0015	0.0002	0.006
Total		108	0.0021	2.48	0.0028	0.0019	0.0001	0.0072

^a:Geometric mean, ^b:Geometric standard deviation, ^c:Arithmetic mean, ^d:Standard deviation, ^e:Minimum, ^f:Maximum

Discussion

A total of 84 workplaces were initially selected to be surveyed, but the results of the survey of 80 workplaces were analyzed, excluding 4 workplaces in which a detailed survey could not be conducted due to the non-cooperative attitude of the employers. The survey showed that 94% of workplaces had ACM (Table 1). Such a distribution rate is higher than the survey result (68%) of buildings in New York City by the US EPA in 1988 [24]. This is due to the fact that more than 90% of the asbestos was used for construction as building materials in Korea. In addition, the import of asbestos-containing products rapidly increased after 1997, and most of the imported products were building materials [19].

The ACM distribution in workplaces did not show a large difference by region; nevertheless, surfacing ACM and TSI showed a significantly low distribution in workplaces in Seoul, Incheon and Jeolla province. This is interpreted as reflecting the difference in employment size in the surveyed workplaces by region. The distribution of small-sized workplaces with less than 50 workers, as surveyed in this research, was 22% and 50% in Seoul, Incheon and Jeolla province, respectively. It was considered that in such small-sized workplaces with less than 50 workers, HVAC systems and soundproofing tend to be poorly equipped and there are few decorations in the buildings, resulting in a low level of surfacing ACM and TSI ACM. In terms of the distribution of ACM by business, only ceiling tiles showed a significantly low distribution in the service industry. This could be attributable to the fact that remodeling operations are frequently implemented for decoration purposes.

In terms of ACM by the type of building material, ceiling tile showed the highest distribution rate, appearing in 84% of the surveyed workplaces, and accounted for 61% of total ACM distribution area. This represents a very different feature from the result of the survey of buildings in New York. In the New York survey [24], TSI ranked first with 68%, while ceiling tile accounted for only 1%. In Korea, rectangular ceiling tiles (60×30 cm²) are very commonly used for the ceiling in most non-residential buildings, and this tile contains 2~10% of asbestos. While most developed countries showed the highest asbestos consumption in the 1970s [29], Korea showed the peak consumption in the 1990s. Asbestos control in Korea started in the late 1990s. The Regulation on Standard for Refuge and Fire Protection from Buildings in Korea stipulates to use noncombustible materials in a building, and the use of asbestos as a representative noncombustible material was allowed until 2005 [30, 31]. Therefore, buildings built before 2005 have high potential to have ACM.

The asbestos industry in Korea was transferred from Japan, but there are big differences between the two countries in the amounts and peak time of asbestos use, as well as the type of asbestos used predominantly in the two countries: chrysotile in Korea and chrysotile with amosite and crocidolite in Japan [32].

Our results also showed that 97.7% of total ACM was chrysotile, while crocidolite was not

detected. Asbestos spraying was rarely used in housing or construction in Korea [32]. Therefore, friable surfacing ACM sprayed or troweled onto structures was rarely found.

In order to identify the priority for ACM management in building materials in workplaces, four characteristics were considered. The first is the ACM distribution by each building material in the workplace, the second is the proportion of each material in the total ACM area in each workplace, the third is the proportion of friable types among ACM by each material, and the last one is the proportion of ACM in local damaged condition by each material. In view of these four factors, the material with the highest priority for routine management was ceiling tiles, followed by roofs, TSI, and surfacing materials.

It cannot be definitely said that the use of asbestos in a building increases the risk of asbestos-related diseases of residents. Lee *et al.* (2008) reported that the potential risk resulting from asbestos was very low after analyzing the asbestos concentration of 3,978 indoor air samples in ACM buildings with transmission electron microscopy (TEM); the mean concentration was 0.00012 fibers/cc, and the result was <0.01 fibers/cc in 99.9% of total samples [33]. In this study, the results of air sampling for asbestos ranged from 0.0001 to 0.0072 fibers/cc, all below the standard for recommendation of indoor air quality in Korea (0.01 fibers/cc) [34]. In the result of ANOVA, there was no significant difference between sampling conditions ($P=0.23$). Nevertheless, in the process of remodeling or maintenance of a building, asbestos is reported to be detected at 0.025 fibers/cc (8hr time-weighted average (TWA)) at the highest [35, 36]. In particular, in Korea, partial destruction of ceiling tiles is implemented frequently for maintenance of ventilation systems or electrical installation in the ceiling, although this type of material has the highest priority for asbestos management. However, currently there is no domestic regulation for controlling ACM in buildings, such as identification of ACM, routine inspection, and the assessment of any potential risk of asbestos exposure. Therefore, this study suggests that the regulation for regular maintenance control of ACM buildings is urgently needed.

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韓国における産業建築物中のアスベスト含有物質と空気中アスベスト濃度

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要 旨: 韓国においては、最近、建築物中のアスベスト含有物質(ACM)の取扱いが環境医学の最重要の問題の一つとなっている。本研究は韓国における産業建築物中のアスベスト含有物質の存在状況と特徴および空気中アスベスト濃度を明らかにする目的で行った。総数1285 検体のアスベストの含有が推定される物質(PACM)の試料を全国の80事業所から収集し、その PACM 試料の40%に 1%以上のアスベストが含まれていた。全般的には、調査した事業所の94%でアスベスト含有物質が存在した。アスベスト含有物質が存在する事業所の分布については、地域、従業員数、事業形態による有意差はなかった。調査した建築物中の総アスベスト含有物質面積は436,710 m²で、天井タイルの ACM がその61%を占め、以下屋根の ACM(32%), 壁面 ACM(6.1%), および暖房システム断熱材(TSI)であった。アスベストの種類については、全 ACM の98%が白石綿(chrysotile)であり、青石綿(crocidolite)は検出されなかった。建材の種類別の比較は、最優先度での定期的管理が必要とされるのは天井タイルであり、次に屋根材、TSI、および壁面材であることを示している。現場の ACM の攪乱が起こらないように採取し、位相差顕微鏡法で解析した空気中アスベストの平均濃度は0.0028 fibers/cc であり、すべての測定で韓国の屋内空気環境についての勧告値(0.01 fibers/cc)よりも下回っていた。

キーワード: アスベスト, アスベスト含有物質, 天井タイル, 管理。

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