Morphology and Size Distribution of Naturally Occurring Asbestos using TEM in Landscape Rock in Parks

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Abstract

Background

Asbestos is a silicate mineral that is naturally generated by geological processes in the Earth's crust. The six types of commercially used asbestos each display the asbestiform crystal habit that is characterized by fibrous aggregates of extremely long, thin crystals. This study provided data that can be used to discriminate asbestiform and non-asbestiform amphiboles contained in landscaping rocks in parks.

Method

In five of the 21 parks, two or more landscaping rocks were found to contain asbestos. These five were selected for additional study. The length and width of fibers being at least 5 μ long and with a minimum aspect ratio of 3:1 were measured using a Transmission Electron Microscope(TEM) and compared to a standard asbestos sample.

Results

The park samples were thicker than 1 μ (average 1.9 μ) while the Health and Safety Executive(HSE) reference sample averaged 0.3 μ in width with 100 % thinner than 1.0 μ . The average aspect ratios were 7.1 for the park samples and 67.1 for the HSE reference sample. The actinolite contained in the landscape rocks of the five selected parks did not show the typical asbestiform structure that was observed in the standard asbestos sample.

Conclusions

Based on these distributions, the amphibole fibers in sampled landscape rocks were found to be thicker and lower aspect ratio than those of the standard sample. The result of this study can contribute to the public policy for managing and controlling of landscaping rocks containing naturally occurring asbestos(NOA) and also to communicate about the possible health risk resulting from NOA contained in landscaping rocks.

Background

Asbestos is a silicate mineral that is naturally generated by geological processes in the Earth's crust. The term asbestos typically refers to six types of widely-used mineral, namely: chrysotile, crocidolite, amosite, anthophyllite, actinolite asbestos, and tremolite asbestos. Of these, chrysotile belongs to the serpentine family of minerals, and the others all belong to the amphiboles [1]. The amphiboles account for about 5% of the minerals that make up the Earth's crust, and can be produced in various forms depending upon the geological environment at the time of mineral formation, such as hot water and metamorphism [2].

The six types of commercially used asbestos each display the asbestiform crystal habit that is characterized by fibrous aggregates of extremely long, thin crystals [3]. Upon observation through an

optical microscope, the asbestiform particle has an average length-to-width ratio (aspect ratio) of between 20:1 and 100:1, with the individual fibers being 5 μm or more in length and generally 0.5 μm or less in width. Additional characteristic features include bundles of fibers that are gathered together in parallel, widely splayed and separated fiber ends, matted masses of individual fibers, or fibers showing curvature [4].

In brief, the majority of particles have an average length-to-width ratio of 20:1 or less, and samples which do not show definite asbestiform properties should not be considered as asbestos [4]. In addition, the U.S. Occupational Safety and Health Administration (OSHA) have excluded the non-asbestiform amphibole minerals (e.g. anthophyllite, actinolite, and tremolite) from the asbestos classification based on the results of epidemiological investigations in which the health hazards of these minerals were not sufficiently verified [5]. Furthermore, several toxicity studies have shown that non-asbestiform amphibole minerals are much less hazardous than asbestiform minerals, and do not appear to increase the occurrence of lung cancer or mesothelioma [6, 7, 8]. Although all forms of asbestos are naturally occurring, asbestos that exists in its natural state in rocks or soil is broadly defined as naturally-occurring asbestos, whereas that which has been extracted from mines and processed for subsequent use is defined as commercial asbestos [9, 10, 11, 12]. Landscape rocks in parks are analyzed for the possible presence of asbestos in accordance with the Ministry of Environment's public notice [13], and any asbestos found therein is classified as naturally occurring. For consistency with their airborne asbestos counting standard, the Ministry of Environment classifies asbestos as a fibrous mineral with particles having a length-to-width ratio of 3:1 or more. Thus, when the airborne asbestos counting standard is applied to the analysis of solid samples, particles with a length-to-width ratio of 20:1 or more (i.e., the standard for solid asbestos analysis)[4] will be classified as asbestos, but so will any elongated non-asbestiform amphibole mineral particles. Although no definite analytical criteria have yet been established to distinguish between asbestiform and non-asbestiform minerals, some studies [3, 14, 15, 16] have attempted to draw this distinction by examining the size distribution and morphological characteristics (e.g., width and length-to-width ratio) of the fibers. Hence, in the present study, landscape rocks were collected from parks and were confirmed as containing asbestos by examination through a polarized light microscope. Particles with a length of 5 μm or more, and length-to-width ratios of 3:1 or more, were further examined through a transmission electron microscope in order to accurately measure their lengths and widths, and to compare them with a standard asbestos sample.

Research Area And Methodology

Research area

Out of the 1,890 parks managed by the Seoul Metropolitan Government, 674 parks have landscaping rocks, and 53 are suspected to have asbestos-containing rocks [17]. Thus, in the present study, samples were collected from a total of 225 sites in the 53 parks where the landscaping rocks were suspected to contain asbestos. These samples were closely analyzed to confirm the presence of asbestos in 21 parks.

In five of the 21 parks, two or more landscaping rocks were found to contain asbestos. These five were therefore selected for additional study.

Sample Collection And Analysis

The surfaces of the landscaping rocks in the 21 parks were visually examined, and three to ten solid samples were collected from those in which a fibrous material or asbestos was suspected. The samples were then analyzed first using a polarized light microscope (PLM) to identify the possible presence of asbestos in 15 samples (approximately 52%) according to the standard criteria. Of these asbestos-confirmed samples, one from each of five parks was then examined by transmission electron microscopy (TEM) to determine the size distribution and morphological characteristics of the fibrous particles (length $\geq 5 \mu\text{m}$, and length-to-width ratio $\geq 3:1$). Following the guidelines of the U.S. Environmental Protection Agency (EPA)[4] for the preparation of solid asbestos samples, the samples were pulverized with a mortar, mixed with a small amount of acetone, and dispersed by ultrasonication for about 5 min. A portion of each sample was then taken with a micropipette and mounted onto a carbon-coated grid for drying. The chemical composition and crystal structure of the fibrous particles were then examined via energy-dispersive X-ray spectroscopy (EDS) and by TEM with selected area electron diffraction (SAED). The maximum length was recorded as the actual length of the particle, and the width was measured perpendicular to the length direction at a representative point on each particle. Amphibole was identified in the SAED analysis based on the repeated appearance of a line with a d-spacing of $5.3 \text{ \AA}$, and the mineral content was further determined based on the elemental composition results obtained in the EDS spectrum until the value of the Si peak reached about 5,000 counts or more. Particularly, only particles having an Al/Si ratio of 1:10 were determined as actinolite to distinguish it from magnesio-hornblende whose chemical composition is very similar. To determine the morphological characteristics of the particles, their length orientations and the shape of their ends were observed. A standard sample of actinolite asbestos from the U.K. Health and Safety Executive (HSE) was selected as an asbestiform sample for comparative analysis, and was pretreated in the same manner as that described above for the landscape rock samples.

Results And Discussion

Morphological characterization

The sample collection and analysis procedure described in the previous section resulted in the detection of actinolite, as indicated in Table 1. The morphological characteristics of representative particle types observed in the park landscape rock samples are compared with those of the standard asbestos sample in Fig. 1. Here, most of the park landscape rock samples display thick and uneven particles, with a completely distinct morphology from that of the standard asbestos sample with its straight, thin, long particles. In addition, the ends of the park landscape rock particles are seen to be uneven and irregular in

shape due to splitting, while the HSE standard samples exhibit predominantly straight, square-ended particles.

Table 1
Characteristics of bulk sample from the landscape rock

Sample	Number of bulk sample	Number of Asbestos-containing bulk sample	Asbestos type by TEM
1	4	2	Actinolite
2	6	3	Actinolite
3	10	4	Actinolite
4	4	3	Actinolite
5	5	3	Actinolite
total	29	15	Actinolite

Particle Width Distribution And Length-to-width Ratio Distribution

The particle-width distributions of the asbestos fibers detected in the landscape rock are compared with those of the standard asbestos samples in Table 2, and the corresponding length-to-width ratio distributions are compared in Table 3. In the case of the landscape rock samples, the average width of the fibers is seen to range from 1.5 to 2.1 μm , with 2–7% of the fibers having widths of 0.5 μm or less, and 11–31% having widths of 1.0 μm or less. Meanwhile, the average length-to-width ratio of the fibers is 6.1–8.2, with 7–21% of the particles having length-to-width ratios of 10:1 or more, and 0–5% having length-to-width ratios of 20:1 or more. In the case of the HSE standard asbestos samples, the average particle width is 0.3 μm , with 98% of the fibers having widths of 0.5 μm or less, and all of the particles having widths of 1.0 μm or less. Further, the average length-to-width ratio of the standard asbestos particles is 67.1, with 99% of the fibers having length-to-width ratios of 10:1 or more, and 96% having length-to-width ratios of 20:1 or more.

Table 2
Width data of actinolite 5 μ m and longer with a minimum aspect ratio of 3:1

Sample	Particles analyzed	Mean (μ m)	Width $\leq 0.5 \mu$ m (%)	Width $\leq 1.0 \mu$ m (%)
1	100	2.1	2	11
2	100	1.9	6	22
3	100	1.5	7	31
4	100	2.1	2	13
5	100	1.8	2	13
HSE Reference Actinolite	100	0.3	98	100

Table 3
Aspect ratio data of actinolite 5 μ m and longer with a minimum aspect ratio of 3:1

Sample	Particles analyzed	Mean (μ m)	Aspect ratio $\geq 10:1$ (%)	Aspect ratio $\geq 20:1$ (%)
1	100	6.1	7	0
2	100	8.0	9	5
3	100	8.2	21	5
4	100	6.8	14	2
5	100	6.4	10	1
HSE Reference Actinolite	100	67.1	99	96

The average width of the five landscaping rock samples is 1.9 μ m, which is almost twice the 1 μ m width that Wylie et al. associated with human health hazards such as cancer or mesothelioma, based on the results of epidemiological studies and animal experiments [6]. Further, their average length-to-width ratio is 7.1, with 95–100% of particles failing to meet the solid asbestos analysis criteria of 20:1, and no separate asbestiform characteristics were identified. Thus, these samples are considered to be non-asbestiform, according to the definition in the solid sample asbestos analysis method of the U.S. EPA [4]. Moreover, only 0–5% of these particles satisfy the asbestiform criteria proposed by Chatfield [13], having widths of 1.5 μ m or less and length-to-width ratios of 20:1 or more. Hence, they are mostly classified as non-asbestiform.

The width and length-to-width ratio distributions of fibrous particles observed in the standard asbestos sample and the landscape rock are further compared in Fig. 2, indicating average widths ($\pm$ the standard deviation) of $0.3 \pm 0.2 \mu$ m and $1.9 \pm 1.1 \mu$ m, respectively. Thus, the width of the standard asbestos samples is much lower than that of the landscape rock samples, with a more uniform distribution.

Further, the average length-to-width ratios ($\pm$ the standard deviation) for the standard asbestos and the landscape rock samples are 67.1 ± 44.8 and 7.1 ± 5.9 , respectively. Thus, the standard asbestos samples exhibit an almost constant particle width regardless of the length, leading to a large variation in the length-to-width ratio, whereas the particle width of the landscape rock samples tends to increase as the length increases, to give a more uniform and smaller length-to-width ratio than that of the standard asbestos sample.

Length Versus Width Correlation

The regression equations and correlation coefficients for the log width (y) versus log length (x) of the landscape rock and the HSE standard asbestos samples are presented in Table 4. According to the classification scheme for the shapes of asbestos particles described by Siegrist and Wylie (1980), the most obvious difference between asbestos fibers and non-asbestiform mineral particles is that the width of asbestos fibers is relatively constant regardless of the length, whereas that of non-asbestiform mineral particles varies as a function of length[18]. In the present work, the length and width of the standard asbestos samples show a low correlation, with a correlation coefficient of 0.297, whereas those of the landscaping rocks exhibit a relatively high correlation, with a correlation coefficient ranging from 0.530 to 0.786. Based on these results, the landscaping rock samples show the characteristics of non-asbestiform mineral particles.

Table 4

Regression equation, correlation coefficient of log width vs. log length

Sample	Regression equation Log width = <i>f</i> (Log length)	Correlation coefficient
1	$Y = 0.8925X - 0.6437$	0.786
2	$Y = 0.7521X - 0.5517$	0.643
3	$Y = 0.8596X - 0.7232$	0.627
4	$Y = 0.7564X - 0.5384$	0.691
5	$Y = 0.7055X - 0.4801$	0.530
HSE Reference Actinolite	$Y = 0.2456X - 0.8328$	0.297

Conclusions

The size distribution and morphological characteristics of actinolite minerals detected in landscape rocks in parks located in Seoul were examined in the present study, including detailed analyses of the particle shapes, widths, and length-to-width ratio distributions, and a comparison with standard asbestos samples. The results indicated that the actinolite contained in the landscape rocks of the five selected

parks did not show the typical asbestiform structure that was observed in the standard asbestos samples. As previous relevant toxicity studies [7, 8] have indicated that non-asbestiform amphibole shows no carcinogenicity, the actinolite contained in the landscaping rocks of the selected parks in this study are judged to be less likely to show these asbestiform-related hazards

It is anticipated that the above analysis of the morphological characteristics of naturally-occurring asbestos contained in landscape rocks will prove useful for determining a reasonable management plan, and as a source of information and reassurance for citizens who are concerned about the presence of naturally-occurring asbestos.

Declarations

- Ethical Approval and Consent to participate

Not applicable

- Consent for publication

Not applicable

- Availability of supporting data

Not applicable

- Competing interests

The authors declare that they have no competing interests

- Funding

Not applicable

- Authors' contributions

JS, GK,SJ, JY, GR, JH and YS analyzed and interpreted the data and write the manuscript.

All authors read and approved the final manuscript

- Acknowledgements

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- Authors' information

JS, GK,SJ, JY, GR, JH and YS: Environmental researcher

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Figures

Figure 1

Examples of particles with nonparallel sides and irregular termination (a, landscape rock) and parallel sides and square termination (b, HSE reference actinolite asbestos)

Figure 1

Examples of particles with nonparallel sides and irregular termination (a, landscape rock) and parallel sides and square termination (b, HSE reference actinolite asbestos)

Figure 1

Examples of particles with nonparallel sides and irregular termination (a, landscape rock) and parallel sides and square termination (b, HSE reference actinolite asbestos)

Figure 2

Box plot of width (a) and aspect ratio (b) for landscape rocks in parks and HSE reference actinolite asbestos

Figure 2

Box plot of width (a) and aspect ratio (b) for landscape rocks in parks and HSE reference actinolite asbestos

Figure 2

Box plot of width (a) and aspect ratio (b) for landscape rocks in parks and HSE reference actinolite asbestos