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The effectiveness of asbestos stabilizers during abrasion of asbestos-cement sheets

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HIGHLIGHTS

- Commercially available asbestos stabilizers significantly differ in binding effectiveness.
- A simple brush abrasion test allows evaluation of the effectiveness of asbestos stabilizers.
- Stabilizers with low (<80%) binding effectiveness should not be used for coating.

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ABSTRACT

The effectiveness of different organic stabilizers in stabilizing asbestos in fiber cement was evaluated using brush-abrasion tests on asbestos-cement (AC) sheets and counting the number of released respirable fibers using phase-contrast microscopy (PCM). All asbestos fibers released from the abraded sheets were identified as chrysotile. The binding effectiveness of the stabilizers varied from 35% (bitumen-based) to >90% (polyurethane resin (PUR), acrylic paint, flexible coating). Stabilizers with low binding efficiency, i.e., <80%, should not be used for coating. The 80% binding efficiency limit is suggested based on the performance of PUR stabilizer applied to the surfaces of AC sheets that were primarily in good condition. With very deteriorated surfaces, even the best performing stabilizers will not prevent fiber release on a scale comparable to that from unprotected sheets in good condition. The greatest effectiveness in binding asbestos fibers is achieved by applying stabilizers that combine a hard coating (PUR), high degree of flexibility (flexible coating) and adhesiveness (acrylic dispersion paint). A simple brush-abrasion test is recommended as an inexpensive, fast and reliable method for evaluating the performance of stabilizers. The brush-abrasion test can reveal invisible deterioration of the cement matrix weakening asbestos-fiber attachment to AC sheets.

1. Introduction

The release of respirable asbestos fibers (length ≥5 µm, width <3 µm, aspect ratio >3:1) from asbestos-containing materials (ACM) when disturbed during repair or removal is of concern because of the potential health hazard to both workers and the public. Whereas some studies have shown very low levels of released asbestos fibers during wet demolition of small buildings [e.g., [1,2]], there is ample evidence of increased levels of inhalable asbestos fibers inside buildings after dismantling and removal of ACM [3–8] (Table 1).

Contamination of both ambient- and indoor air with asbestos may result from factors hindering control over the release of mineral dust during ACM removal, e.g., improper handling of ACM, lack of pressure relief units, failure to meet the required air-exchange regimes in the workplace or careless final cleaning. The desire to reduce operating costs by contractors may also lead to improper dismantling procedures. In addition, exterior ACM are subject to long-term weathering which may promote the release of asbestos fibers into the air [9,10]. Dissolution of the cement matrix within surficial layers of asbestos-cement (AC) sheets as a result of weathering can increase asbestos-fiber concentrations from 13 to 15% in unweathered sheets to 20% in weathered sheets (Fig. 1).

There are two primary ways of handling ACM to minimalize the risk of asbestos-fiber release, namely, (a) removal of ACM and replacement by non-asbestos materials and (b) enclosing, sealing or encapsulating ACM left in place. Sealing can be accomplished

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Table 1
Respirable asbestos-fiber concentrations (f/m^3) in five rooms of an industrial building before and 48 h after removal of friable ACM.

Room	Before removal	After removal
1	1000–1400	4000
2	900	3200
3	1600	2800
4	1000–1600	2800
5	1000–2500	3500

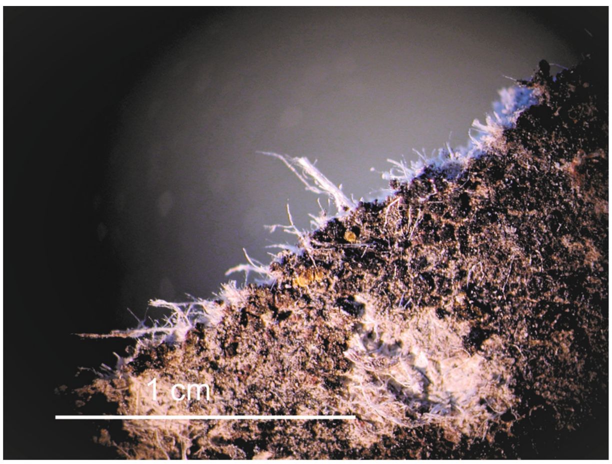

Fig. 1. Loosely bonded bundles of chrysotile fibers exposed in a highly deteriorated corrugated AC roofing sheet. The AC sheet was exposed to the atmosphere for 20 years in a region of Upper Silesia, Poland, known for acid rain.

by coating the surface of the ACM with special polymeric-, bituminous- or cement-based paint [e.g., [11]] or by using deep-penetrating stabilizers [[12,13] and references therein].

Removal of ACM is the preferred solution to the problem of ACM management. However, removal is more expensive and if done improperly, may result in the emission of large numbers of respirable asbestos fibers. Therefore, if the condition of ACM is good and the indoor concentrations of airborne asbestos fibers are low, the best action may well be to protect the ACM with stabilizers (encapsulants) rather than removal [8,12–14].

Treatment of ACM with stabilizers is advantageous for two main reasons; it increases the durability of ACM and prevents or limits the emission of asbestos-containing dust during dismantling and transport. However, for economic reasons, wetting of the surfaces of dismantled ACM with water is often employed. While cheaper than impregnation with stabilizers, wetting is disadvantageous as it only prevents the ACM from releasing unbound asbestos for a relatively short time due to water evaporation. For example, it has been shown experimentally that water-wetting of asbestos (chrysotile) rope, a friable material, is ten times less effective in preventing the release of respirable fibers than impregnation with a stabilizer [15]. Unlike water, asbestos stabilizers act as film-forming binders, fixing fibers even after evaporation of their volatile fraction. Recently, Jung et al. [13] have shown that both the surface condition of asbestos-containing ceiling tiles and treatment with stabilizers are the major factors controlling the number of fibers released during wind tests; airborne asbestos fiber concentrations released from damaged ceiling tiles treated with stabilizers decreased by 69.5–84.5% as compared to untreated tiles.

To check the effectiveness of various binders, and to allow their use in Poland, a procedure for issuing approval certificates based on laboratory measurements of numerous physical parameters, *inter alia*, drying time, adhesion of the stabilizer to the substrate, flexibility during forced aging and steam diffusion resistance was developed in 2005 [16]. The procedure turned out to be too complicated and costly for implementation by asbestos-removal companies. Currently, the use of stabilizers is not mandatory in Poland and, as a result, ACM are usually not treated with stabilizers. The problem is not trivial as the area of building facades and roofs covered by AC sheets in Poland is estimated to be 1.5 billion square meters [17–20]. Out of an estimated 15.5 $\times$ 10^6 Mg of ACM in use in Poland in 2002, only about 10% (~1.57 $\times$ 10^6 Mg) had been removed and disposed of within the framework of the national asbestos abatement program by the end of 2013 [21].

While there is a wide range of stabilizers on the market [e.g., [12]], they have different binding properties and, thus, their levels of effectiveness in binding asbestos fibers in AC sheets may vary significantly. In this paper, we present the results of a simple experiment enabling quantitative evaluation of the effectiveness of stabilizers by comparing the numbers of respirable asbestos fibers released during brush-abrasion of AC sheets treated with various stabilizers to the numbers released from untreated samples.

2. Experimental methods

Four sets of flat AC sheets, removed from the different roofs being dismantled, were supplied by the manufacturers of the stabilizers. Sample sizes were 15 $\times$ 15 cm^2 or 20 $\times$ 20 cm^2. From each set, samples without treatment and samples with two coats of brush-applied stabilizers were submitted to the brush-abrasion test. The experiment was designed to compare the results of the brush-abrasion tests within each set separately. Visual inspection of untreated AC sheets revealed no signs of weathering or mechanical damage. The stabilizers evaluated were (a) polyurethane resin (PUR), (b) acrylic dispersion paint, (c) asphalt-based stabilizer with and without primer, and (d) a flexible coating based on polyethylene, polyvinyl chloride and acrylic. Some properties of these products as determined by the manufacturers are given in Table 2. Only one manufacturer supplied AC sheets coated with three different stabilizers. Others provided AC sheets coated with their own individual products.

The experimental set up is shown in Fig. 2. The AC sheets were placed on a rotating sample holder and abraded with a counter-rotating steel wire brush. The rotation speed (100 rpm) and the force of the steel wire brush (weight 500 g) were exactly the same for all experimental runs. The AC sheets of the first set were abraded for 50 min. To avoid overloading filters with asbestos fibers, the AC sheets of other sets were abraded for 30 min. The abraded areas were 100 cm^2. During abrasion, asbestos fibers were collected with a filter suction device at a flow rate of 10 l/min through the sampling cassette containing a 0.8 µm pore filter positioned 15 cm above the abraded surface.

The AC sheet, the wire brush and the filter-containing cassette were enclosed in a 60-liter glass dome. During brush abrasion, fiber concentrations expressed as fibers per cubic meter (f/m^3)

Table 2
Selected parameters of stabilizers used in this study.

Stabilizer	Adhesion MPa	Elasticity mm	Density gcm^{-1}
Asphalt-based without a primer	≥1	>2	NA
Asphalt-based with a primer	≥2	>2	NA
Polyurethane resin	≥5	≤5	0,9
Acrylic dispersion paint	≥2.5	≤3	1.2
F-C flexible coating	≥1	<5	1.3–1.4

Data provided by the stabilizer manufacturer. NA – data not available.

Fig. 2. The experimental set up. (1) AC sheet. (2) Steel wire brush. (3) Filter cassette. (4) Rotating sample holder. (5) Air pump. (6) Electronic controller used to synchronize the frequency of rotation of sample holder and wire brush.

were determined in accordance with the Polish PN-88/Z-04-20/02 and AIA RTM 1 standards using phase contrast microscopy (PCM). A Carl Zeiss Jena JENAPOL polarized-light microscope equipped with phase contrast objectives was used. A perfect match between the observed optical properties of the investigated fibers (curly fiber morphology, positive sign of elongation, parallel extinction, low refraction index and low birefringence resulting in gray interference color) and the McCrone reference chrysotile asbestos was achieved.

The effectiveness of the binding of the asbestos fibers (Ef) by the stabilizers was calculated using the formula

$$E_f[\%] = [1 - (C_T/C_U)] \times 100$$

where C_T is the concentration of respirable airborne asbestos fibers released from AC sheets treated with a stabilizer, and C_U the concentration of respirable airborne asbestos fibers released from the corresponding untreated sheets. The emission reduction factor (ERF) was calculated as the number of fibers released from the untreated AC sheet divided by the number of fibers released from the corresponding AC sheet treated with a stabilizer.

3. Results and discussion

All asbestos fibers released from the abraded AC sheets were identified as chrysotile, ($Mg_3Si_2O_5(OH)_4$). Chrysotile fiber concentrations are given in Table 3. While the untreated sheets showed no visual signs of damage and deterioration, the abrasion tests revealed significant differences in their surface quality (Table 3). For instance, the number of fibers (135 700f/m^3) released from an untreated Set 3 sheet brush-abraded for 30 min is about twenty times higher than the number of fibers (5900f/m^3) released in the same time interval from a Set 4 sample (Table 3). This observation confirms previous results indicating that the quality of the AC-sheet surface is the principal factor influencing susceptibility to fiber release upon mechanical damage [13,22]. However, the data also shows that visual inspection may be misleading when evaluating the condition of AC sheets if evident signs of weathering are absent, e.g., loosely bound fibers exposed on the surface due to the dissolution of the cement matrix. Differences in the actual condition of untreated AC sheets ranging from good (Sets 1 and 4) through weathered (Set 2) to highly weathered (Set 3) revealed by brush abrasion had gone unnoticed during visual evaluation.

Treatment with stabilizers significantly decreased the amount of asbestos fibers released from AC sheets (Table 3). The PUR stabilizer, the flexible coating and the acrylic dispersion paint all proved effective in preventing asbestos fiber emission, the asphalt-based stabilizers much less so (Table 3). The PUR stabilizer binding effectiveness is lower when applied to an unweathered AC sheet ($E_f \sim 80\%$) as opposed to a weathered sheet ($E_f \sim 95\%$). This behavior may reflect binding properties of the cement matrix in unweathered AC sheets which are enough to prevent asbestos-fiber release during abrasion. In fact, the number of asbestos fibers released from the untreated AC sheet initially in good condition (Set 1 in Table 3) is an order of magnitude lower than from the weathered sheet and two orders of magnitude lower than from the highly weathered sheet (Set 3) despite the much longer (+20 min) abrasion time for the unweathered sheet (Table 3). Although the binding effectiveness of the acrylic dispersion paint is very high (E_f = 95–96%), the number of asbestos fibers released during 30 min brush-abrasion of painted heavily weathered AC sheets (5300–7200f/m^3) is comparable to the number released after 50 min from the untreated AC sheet initially in good condition (Table 3). Hence, special care is required during the dismantling of AC sheets with highly deteriorated surfaces, even if thoroughly impregnated with highly efficient stabilizers. In their wind-tests, Jung et al. [13] showed that the effectiveness of organic- and synthetic-resin stabilizers in binding asbestos fibers was twice that of inorganic stabilizers. Our study shows that even among organic stabilizers, binding properties can be highly variable. The ERF decreases slightly with increasing distance from the brush-abraded surface of the AC sheet coated with binders (Table 4), perhaps as a result of dispersion of fibers released into the air.

To illustrate the consequences of differences in the binding properties of various stabilizers, we have used data obtained during this study to simulate real-life situations (Fig. 3). PCM concentrations of respirable asbestos fibers were measured during the removal of AC corrugated sheets from a roof area of 35 m^2. The surfaces of the AC sheets were in good condition. The AC sheets were

Table 3
Concentrations of respirable asbestos (chrysotile) fibers released during abrasion of flat AC sheets untreated and treated with various stabilizers, the effectiveness of asbestos fibers binding (E_f), and the emission reduction factor (ERF).

Sets of AC sheets	Stabilizer	Concentration [f/m^3]	Duration [min]	E_f [%]	ERF
1	untreated AC sheet	7900	50	–	–
	asphalt-based without a primer	5100	50	35	1.5
	asphalt-based with a primer	4000	50	49	2.0
	polyurethane resin	1400	50	82	5.6
		1500	50	80	4.9
2	untreated AC sheet	22 230	30	–	–
	polyurethane resin	1930	30	91	11
		1090	30	95	20
3	untreated AC sheet	135 700	30	–	–
	acrylic dispersion paint	7200	30	95	19
		5300	30	96	26
4	untreated AC sheet	5900	30	–	–
	F-C flexible coating	500	30	91.5	12

Table 4
Asbestos fiber concentrations (f/m^3) related to the distance from the abraded flat AC sheets untreated and treated with two different organic stabilizers (A and B).

Distance [cm]	Untreated AC	AC treated with stabilizer:		E_f (%)	ERF
		A	B		
5	15 780	5490	–	65	2.9
10	13 380	4970	–	63	2.7
5	11 120	–	2300	79	4.8
15	5840	–	1630	72	3.6

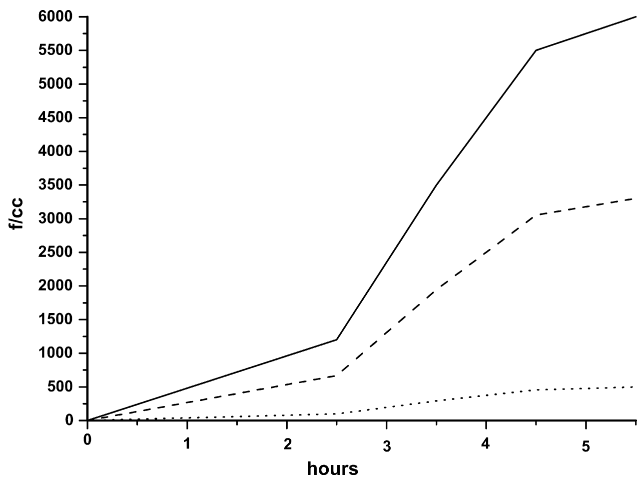

Fig. 3. Time-related changes in the concentration of respirable asbestos fibers released during removal of AC corrugated sheets from a roof (solid line). The air was sampled 5 m from the roof surface. Dashed- and dotted lines show the expected concentrations of asbestos fibers if the AC sheets were treated with bitumen-based and flexible coatings, respectively.

wetted with water before removal. Air was sampled 5 m away from the workplace at hourly intervals beginning 2.5 h after the start of the removal process. The number of asbestos fibers increased gradually up to 6000f/m^3 after 5.5 h of dismantling (Fig. 3). If the AC sheets had been stabilized with a bitumen-based coating or with a flexible coating, the estimated number of the released fibers after 5.5 h would have been slightly above 3000f/m^3 and 500f/m^3, respectively. Even the poorest-performing stabilizer would decrease the amount of released inhalable fibers by half. For safety reasons, the obvious choice is to apply the most efficient stabilizer.

The binding effectiveness of stabilizers decreases with time as was shown by Foltyn and Obmiński [15]. In their experiments, asbestos fibers released from a pure chrysotile rope treated with a stabilizer were reduced 192 times relative to the untreated rope immediately after the treatment. However, after 24 and 48 h, the ERF of the fibers decreased to 92 and 14 times, respectively. Nevertheless, these values are still an order of magnitude higher than the ERF of water-wetted rope; in that case, emission was 9 times lower after 24 h.

4. Conclusions

This study confirms the results obtained by previous investigators that commercially available stabilizers can significantly reduce the number of respirable asbestos fibers released during mechanical damage to the surface of ACM. However, the binding effectiveness of commercially available stabilizers can vary from 35 to 96%. In our opinion, stabilizers with binding effectiveness <80%, should not be used, particularly on highly deteriorated surfaces. The suggested 80% limit is based on the performance of the PUR stabilizer on unweathered AC sheets. Even the best-performing stabilizers do not prevent fiber emission from highly deteriorated surfaces on a scale comparable to that from unprotected AC sheets in good condition.

The greatest effectiveness in binding asbestos fibers is achieved by applying stabilizers that combine a hard coating (PUR), high degree of flexibility (flexible coating) and adhesiveness (acrylic dispersion paint). Binders should be applied not only with the safe use of ACM in mind but also the protection of workers involved in their dismantling.

A simple brush-abrasion test that measures the amount of respirable asbestos fibers released from mechanically damaged ACM treated with a variety of stabilizers is recommended as an inexpensive, fast and reliable method for evaluating stabilizer performance. Unlike visual inspection, the abrasion test is an objective measure of the degree to which cement-matrix deterioration weakens the bonding between asbestos fibers and the matrix, enabling the mass emission of fibers.

CRediT authorship contribution statement

Andrzej Obmiński: Conceptualization, Funding acquisition, Methodology, Visualization, Writing - original draft. **Janusz Janeczek:** Formal analysis, Visualization, Writing - original draft, Writing - review & editing.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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