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Risk Assessment of the Decay of Asbestos Cement Roofs

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Objectives: In an assessment of the risk of asbestos fibres release from asbestos cement materials, an important role is played by the assessment of the surface corrosion and by the disaggregation of asbestos cement. The aim of this work is to evaluate the differences among several methods used for the risk assessment that lead to a specific choice of abatement techniques.

Methods: The state of deterioration of 40 asbestos cement roofs was evaluated using two priority assessment algorithms elaborated in Italy, the 'pull-up test' described by the Italian Organization for Standardization and the indicators described in the Italian legislation coupled with the observation of a small sample, taken from each roof, by a stereomicroscope.

Results: The results obtained with the methods, proposed in this study, for the risk assessment of the decay of asbestos cement roofs show slight differences among them, only one deviates from the others in judgement on the state of conservation of the roof.

Conclusions: It is very important to train the operator conducting the study since a completely subjectivity-free method does not exist. Whatever method is used will always be affected by the subjectivity linked to the competency and the training of the operator. Moreover, each method on its own cannot assess the risk of exposure to asbestos, but reliable assessment of asbestos-containing materials requires the use of more than one method, such as visual inspections, a pull-up test, and an assessment algorithm.

Keywords: asbestos cement roof; priority assessment algorithm; pull-up test; risk assessment; SEM

INTRODUCTION

The industrial manufacture of asbestos-containing materials (ACM) dates back to the end of the 1800s. Asbestos is a stable mineral, non-flammable mineral, which is acid resistant, flexible, traction resistant, elastic, easily spinnable, and sound absorbent.

The characteristics of this material and its low cost brought about its widespread use mixed with other minerals, with the aim of best exploiting its characteristics.

The largest industrial use of asbestos, at worldwide level, was in combination with cement, for the construction of a wide variety of products, such as, for example, pipelines or flat and corrugated sheets. Other important uses for asbestos were the production of asphalt- or vinyl-based products for road surfacing, isolating products for pipelines and boilers, fire sprinkler products, and electrical insulators.

Among ACM, asbestos cement sheets are the most common in Italy; they were widely used for roofing materials in different categories of buildings, both in agricultural and in residential areas. It is estimated that in Italy between 1984 and 1988, only 3 million tonnes of asbestos cement products were used, 0.5 million of which were used in chimney flues, pipes, and mains and the remaining 2.5 million were used for roofing.

During the production of flat and corrugated asbestos cement sheets used for roofing buildings, the

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asbestos is incorporated into a cement matrix, which, when kept in good condition, limits the spontaneous release of fibres and so these materials do not represent an important source of pollution. Ordinary Portland cement was used for the production of asbestos cement sheets, in percentages varying between 84 and 90%, depending on its final use. It was enriched with tricalcium silicate ($3CaSiO_2$) to ensure a higher resistance to pressure or with dicalcium silicate ($2CaOSiO_2$) to obtain a greater sheet plasticity.

The mechanical performance of cementitious matrix without a fibrous reinforcement is rather mediocre. On the other hand, mixing it with a certain quantity of fibres helps give a significant increase in its resistance and above all in toughness. The capacity of asbestos fibres to reinforce cement depends on their length, on their capacity to create interfacial links with the matrix, on the volume of the fibres (there is a critical volume that is the minimum content of fibre which is capable of supporting stress beyond the break point of the matrix), and on the degree of fibre alignment in the cement matrix (Chiappino and Venerandi, 1991).

In Italy until 1986, both chrysotile and amphibole asbestos were used in ACM. Subsequently, due to the high health risks associated with the use of amphiboles, the production of asbestos cement sheets used only chrysotile, introducing a fibre mix of longer chrysotile, like the Canadian mix.

Asbestos cement roofing sheets are exposed to the elements once they are put in the roof, so they are subject to deterioration from installation, which leads to a disaggregation of asbestos cement, becoming the most widespread sources of airborne toxic asbestos fibres. This takes place in variable quantities, depending on exposure to atmospheric agents and on fractures due to indirect (vibrations, etc.) or direct (maintenance interventions, demolition, or acts of vandalism) mechanical action.

In the long run, the action of water, sun, ice, wind, moss, and lichen, or pollutants such as sulphur dioxide, acid rain, etc., can cause corrosion that facilitates the gradual release of asbestos fibres. Water, for example, causes the dissolution of soluble salts and the subsequent leaching of calcium hydroxide, causing an increase in the porosity of the material and an increase in the speed of the subsequent disintegration (Carde *et al.*, 1996; Faucon *et al.*, 1996; Haga *et al.*, 2005).

In the presence of CO_2, calcium carbonate is formed (carbonation). This is much less soluble than the corresponding hydroxide which possesses a higher specific volume and can cause micro fissures. In this transformation, more water is liberated and more calcium carbonate is formed, always in the presence of CO_2 (Dias *et al.*, 2008).

The damaging action of rain, due to the presence of acid radicals, such as sulphuric and nitric acid, results in a rapid dissolution of the calcium and also the disintegration of aluminates present in cement. It has been widely reported in cement-based materials (Zivica and Bajza, 2001; Xie *et al.*, 2004; Beddoe and Dorner, 2005). The strong sulphuric and nitric acids react with the chemical structure of the cement, due to the displacement of the weaker silicic acid, causing the transformation of the calcium silicate, which is insoluble in water, into calcium sulphate or calcium nitrate, which are soluble. The result is a surface corrosion with the erosive removal of subsequent layers of dissolved cement which in this way facilitates the asbestos release. The deterioration of the composite is also aided by sudden thermal changes. The transformation of water into ice in the cavities present in a cement structure causes a disintegration effect due to the relative increase in volume (Haga *et al.*, 2005; Dias *et al.*, 2008).

The surface layer of the corroded manufactured matrix becomes a colonization centre for plant organisms such as moss and lichen, which, by keeping the water in contact with the cement for a long time, contribute to the further decay of the surface, although in recent papers it was reported that lichens have a weathering and covering role (Favero-Longo *et al.*, 2006, 2007; Turci *et al.*, 2007).

The final outcome of all these phenomena leads to the formation of a surface layer which is rich in fibres that are easily liberated into the environment.

During the assessment of the risk of asbestos fibres release from ACM, an important role is played by the assessment of the surface corrosion. Presence of cracks and other mechanical damage should be taken into consideration as important factors. The classification of decay of the material is based on a visual survey carried out by an experienced surveyor. The survey classifies the ACM into three classes: intact materials not susceptible to damage, materials susceptible to damage, and damaged materials. In order to verify the release of asbestos fibres, the visual survey should be accompanied by air sampling that allows the choice of action to undertake in face of ACM.

Sometimes, in order to limit the subjectivity, it is preferable to use the so-called point systems, in which the risk of the release of fibres can be summarized in a mathematical algorithm.

This work compares the different methods used for the risk assessment in order to study the differences among them in the choice of abatement method that must be taken.

MATERIAL AND METHODS

The main legal provisions in force in Italy regarding asbestos cement roofs are the following:

- The Ministry of Health Decree of the 6th of September 1994 regarding regulations and technical methods for risk assessment, inspections, maintenance, and abatement of materials containing asbestos in building structures (Italian Ministry of Health, DM 1994).

- The Ministry of Health Decree of the 14th of May 1996 regarding regulations and technical methods for abatement operations (Italian Ministry of Health, DM 1996).
- The Ministry of Health Decree of the 20th of August 1999 for the widening of regulations and technical methods for abatement operations (Italian Ministry of Health, DM 1999).

The Ministerial Decree of 1994 identifies the criteria for a thorough assessment of the state of the materials, risks, inspections, maintenance, and abatement, as shown in the flow chart in Fig. 1. These criteria were adopted and integrated into the Ministerial Decree of 1999.

According to these two decrees, the decision process for the choice of action to undertake in the face of ACM is based on the classification of these materials into three classes: intact materials not susceptible to damage, materials susceptible to damage, and damaged materials. The Ministerial Decree of 1994 indicates, to this end, a series of parameters regarding the identification of the state of the materials and the extent of possible damage. The main indicators that are useful in the assessment of decay of asbestos cement roofs, relating to the potential release of fibres, are

- the friability of the material;
- the state of the surfaces and in particular the presence of zones where asbestos fibres are surfacing;
- crumbling, cracks, or breakages;
- friable or pulverulent material next to eaves, gutters, etc. (Fig. 2);
- the presence of collections of materials forming small stalactites corresponding to seepage points (Fig. 3).

Our study evaluated the roofs in 40 buildings from various categories (public, agricultural, and industrial).

The methods used to evaluate the conservation state of the asbestos cement roofs were the following:

1. Two priority assessment algorithms elaborated in Italy; one introduced in the Regional Asbestos Plan by the Tuscan Region (Delibera Consiglio Regionale Toscana, 1997) that we will name A algorithm and one set out by the Emilia Romagna Region (Brun *et al.* 2002) that we will name B algorithm. Both algorithms were integrated in Regional Plan for Protection Asbestos of the originating region.
2. The 'pull-up test' using a special adhesive tape as described by the Italian Organization for Standardization (UNI 10608, 1997). The adhesive tape is applied on the corrugated and flat roof sheets. Regulation UNI 10608 allows evaluation of the disaggregation of asbestos cement on the basis of the

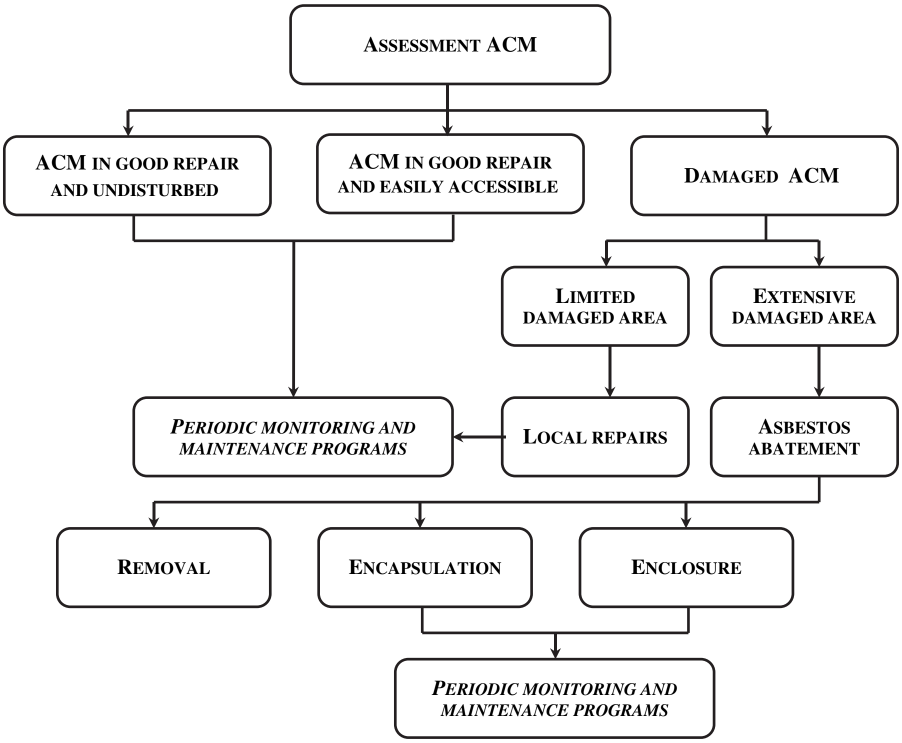

Fig. 1. Flow chart of ACM assessment.

quantity of material stuck to the adhesive tape expressed as gram per square centimetre. The collected material undergoes a gravimetric analysis and the classification is the following one: very good, good, poor, and very poor.

3. The indicators described in the Ministerial Decree of 1994 (Italian Ministry of Health, DM 1994) coupled with the observation of a small sample, taken from each roof, by a stereomicroscope (Olympus SZX). The observation by stereomicroscope permitted the detection of the abundance of the exposed asbestos fibres on the surface of the sheet. Judgement of good, poor, and very poor, according to the conservation state of the examined material, was awarded.

In order to apply the pull-up test, the analysed surfaces must be dry (at least 48 h should have passed since the last episode of rain) and the sheets should not have been subjected to prior cleaning procedures. In the case of sheets that showed notable signs of moss, lichen, or mould, sampling took place in areas free of the latter. For each roof, at least three pieces of adhesive tape were used. For the flat sheets, the adhesive tape was positioned parallel to one of the two sides for at least 20 cm avoiding overlapping. For the corrugated sheets, the adhesive tape was applied across the curve, for at least two complete curves (Fig. 4). After application, the adhesive tape was pulled delicately and was finally folded again on itself to avoid the loss of the collected material.

The material stuck to the tape was first weighed using Sartorius MC1 precision balance (limit: 210 g; format unit u_f: 0.01 mg) and then, on the basis of the quantity of material stuck to the adhesive tape, a judgement of the conservation state of the roof was awarded. Some of these tapes were observed using a scanning electron microscope (SEM: LEO 440) combined with an energy dispersive X-ray spectroscopy (EDS: Oxford Instrument INCA) which allows the chemical characterization of asbestos fibres.

Air sampling was carried out using static samplers (Analitica Airflow 300T) with a flow rate of 10 l min^{-1} for sampling variable air volumes but not <3.000 l. The airborne particulate was sampled using 25 mm diameter and 0.8 μm porosity polycarbonate membrane filters. The sampling and analysis were carried out according to the Asbestos International Association (AIA, 1984) standard guidelines for the airborne asbestos fibres and Italian regulation (Italian Ministry of Health, DM 1994).

The concentration of the airborne asbestos fibres was measured by analysing the sampling membranes using the SEM. The observation area for each filter was 1 mm^2 and examination was carried out at

Fig. 2. Friable material in the gutter.

Fig. 3. Stalactite formed in the seepage points.

Fig. 4. Example of sampling by pull-up test.

a magnification of ×2000. All the fibres detected in the observation areas and which were of a respirable dimension (diameter < 3 μm, length > 5 μm, length:diameter ratio > 3) were analysed by EDS.

RESULTS

Tables 1 and 2 show the A and B algorithms, respectively, used for the assessment of decay of the asbestos cement roofs.

The algorithm calculation in the first case (Table 1) is the following:Materials with total scores of ≥55 should be regarded as a high risk with a significant potential to release fibres and therefore the roofs are be removed.

Scores between 27 and 54 are regarded as medium risk and the roofs are to be encapsulated with water-resistant products. Scores between 10 and 26 are regarded as low risk and the roofs are to be left where they are.

The second case (Table 2) represents a simplified additive algorithm that assesses five parameters where each parameter is scored and the value assigned is added together to give a total score between 5 and 27. Material assessment with total scores between 21 and 27 is classified as very poor, and in this case, within 18 months, asbestos abatement procedure should be adopted (preferably removal technique). The asbestos materials near the schools are to be removed within 6 months. Materials with scores between 11 and 20 are classified as poor and the conservation state of the asbestos cement roofing is to be yearly evaluated. Asbestos abatement operations should be performed within 3 years; in the proximity of the schools, these operations are to be completed within 1 year. The type of operation is not indicated however. Finally, materials with scores between 5 and 10 are classified as fair and in this case is not necessary abatement operation. They will be checked every 3 years.

The results of the roofs examined with two algorithms, the pull-up test and the indicators described in Decree of 1994 coupled with the observation to stereomicroscope, are shown in Table 3. In the

Table 1. 'A' algorithm used for the evaluation of the state of deterioration of asbestos cement roofs

Assessment parameter	Score	Example of score variables
A—State of conservation	1	The visible layers of fibres are almost completely incorporated in the cement matrix
	2	They are enclosed only partially
	3	They are easily removable with tweezers
B—Presence of cracks	1	Absent
	2	Rare
	3	Numerous
C—Type of asbestos	1	Only chrysotile
	4	Amphibole or mixed chrysotile and amphibole
D—Friability	1	The corners or the edges of the sheets break with a sharp sound using pincers
	2	The break of the corners of the sheets is easy and it has a dull sound
E—Surface release	1	Particles are not released from the surface when rubbed with a latex glove
	2	Particles are released from the surface when rubbed with a latex glove
F—Accessibility	1	The roof is not accessible
	2	The roof has potential rights of passage
	3	The roof is easily accessible
G—Support structure	1	The roof rests on a load-bearing loft
	2	The roof rests on beams
H—Distance from the windows	1	The roof is far from windows
	4	There are overlooking or adjoining windows or terraces
I—Frequency of access	1	There are never access to the roof
	2	There is occasional access to the roof
	3	There is frequent access to the roof
V—Age	2	Up to 10 years of age
	3	From 11 to 30
	4	>30

Table 2. 'B' algorithm used for the evaluation of the state of deterioration of asbestos cement roofs

Assessment parameter	Score	Example of score variables
Material solidity	1	The corners or the edges of the sheets break with a sharp sound using pincers
	3	The corners or the edges of the sheets tend to bend or flake using pincers
	9	The corners or the edges bend or flake easily when manipulated by hand
Appearance of fibres	1	Enclosed bundles of fibres can be seen in the cement matrix using a magnifying glass
	3	Partially enclosed bundles of fibres can be seen in the cement matrix using a magnifying glass
	9	The layers of fibres seen using a magnifying glass are easily removable using tweezers
Flaking, cracks, breakages	1	Absent
	2	Not very frequent
	3	Numerous
Friable or pulverulent material in the gutter	1	Absent
	2	Scarce
	3	Substantial
Stalactites	1	Absent
	2	Small size
	3	Substantial size
	Total Sum	Judgement on the state of conservation of the roof

columns of two algorithms, the total score is shown in parentheses.

The results obtained with the different methods, proposed in this study, for the risk assessment of decay asbestos cement roofs show slight differences, only the B algorithm deviates from other assessment methods in final judgement on the state of conservation of the roof. The B algorithm, in fact, classifies ~57% of studied roofs as poor (in this case abatement is not necessary); the same roofs are almost all classified as a high risk with the A algorithm and therefore they are to be removed. The results obtained by priority assessment A algorithm are in accordance with the judgements mediocre or very poor obtained by the pull-up test and with visual survey by indicators coupled with stereo analysis.

Figures 5–10 show the SEM images with some EDS analysis of the material stuck to the adhesive tape with the pull-up test. In the case of 'very poor' classification, the material has undergone the effects of leaching and the asbestos fibres are completely free from the cement. Figures 5 and 7 show amosite and chrysotile fibres, respectively, with their EDS spectrum (Figs 6 and 8).

Figures 9 and 10 show, respectively, the materials classified as 'poor' where the asbestos fibres are still bound with cement matrix and the materials classified as 'good' where the fibres are completely enclosed.

Table 4 shows the concentrations of airborne asbestos fibres measured in the areas adjacent to the 20 buildings in which extensive asbestos cement roofing was found. Among these, 2 roofs were public buildings, 11 industrial buildings, and 7 industrial disused sites, which showed roofing in visibly advanced states of degradation. The pull-up test applied to public and industrial buildings judged the roofs as very poor. The air samplings were performed at a height of ~1.5 m from the ground and at a distance of ~3–4 m from the building. The mean wind velocity was always very slow of ~1–2 m s^{-1}.

Table 4 shows also the number of air samplings that were carried out and the mean concentration values of airborne asbestos fibres with the lower (λ_L) and upper confidence limits (λ_U) for the Poisson distribution with a 95% probability.

Despite the high deterioration of roofing, the levels of airborne asbestos are low and comparable with those proposed by the World Health Organization (WHO) in urban areas. In fact, the WHO gives reference data for pollution by asbestos. In rural areas, i.e. in zones far away from man-made sources of emission, the concentrations are <0.1 f l^{-1}, while in urban areas the pollution levels vary from values <0.1 f l^{-1} to ~1 f l^{-1}, the latter corresponding to zones with heavy traffic (WHO, 2000).

If we consider the upper confidence limit, we see that the 9% of the calculated concentrations are lower than the detection limit, that is the limit value below which the concentration must lie when no fibre is found during SEM analysis. A detection limit of 0.4 f l^{-1} was assumed on the basis of 1 mm^2 of analysed filter area and a sample air volume of 3000 l (VDI, 1991). The airborne asbestos concentrations are equal to 1 f l^{-1} in 43% and they are >1 f l^{-1} in 48% of measurements carried out. All the asbestos

Table 3. Comparison of the results obtained from different risk assessment methods

Roof	'A' algorithm	'B' algorithm	Pull-up test	Visual survey and observation by a stereomicroscope
1	Encapsulate (51)	Fair (9)	Good	Mediocre
2	Remove (60)	Poor (15)	Very poor	Very poor
3	Encapsulate (48)	Poor (12)	Poor	Mediocre
4	Remove (75)	Poor (20)	Very poor	Very poor
5	Remove (54)	Poor (14)	Good	Very poor
6	encapsulate (45)	Fair (6)	Very good	Good
7	Remove (57)	Fair (7)	Very poor	Good
8	Encapsulate (48)	Poor (14)	Very poor	Very poor
9	Encapsulate (48)	Fair (8)	Poor	Mediocre
10	Encapsulate (51)	Fair (8)	Good	Very poor
11	Remove (57)	Fair (7)	Good	Good
12	Remove (84)	Poor (18)	Poor	Very poor
13	Remove (72)	Poor (17)	Very poor	Very poor
14	Encapsulate (51)	Poor (17)	Poor	Very poor
15	Encapsulate (42)	Fair (9)	Good	Mediocre
16	Remove (72)	Fair (8)	Very poor	Mediocre–very poor
17	Encapsulate (51)	Poor (18)	Poor	Very poor
18	Remove (76)	Very poor (23)	poor	Mediocre–very poor
19	Encapsulate (54)	Fair (15)	Very poor	Mediocre–very poor
20	Encapsulate (54)	Poor (15)	Very poor	Very poor
21	Encapsulate (48)	Fair (8)	Good	Mediocre
22	Remove (60)	Poor (14)	Very poor	Very poor
23	Encapsulate (51)	Fair (8)	Poor	Mediocre
24	Encapsulate (48)	Poor (12)	Poor	Very poor
25	Remove (75)	Poor (20)	Very poor	Very poor
26	Remove (60)	Poor (14)	Very poor	Mediocre
27	Encapsulate (54)	Fair (7)	Poor	Mediocre
28	Encapsulate (51)	Poor (14)	Poor	Very poor
29	Remove (72)	Poor (18)	Very poor	Mediocre
30	Remove (60)	Poor (17)	Very poor	Mediocre
31	Remove (75)	Fair (8)	Poor	Very poor
32	Encapsulate (45)	Poor (15)	Poor	Mediocre
33	Remove (72)	Poor (14)	Very poor	Very poor
34	Encapsulate (54)	Fair (7)	Poor	Good
35	Encapsulate (51)	Poor (14)	Poor	Mediocre
36	Remove (60)	Poor (15)	Very poor	Mediocre
37	Encapsulate (51)	Poor (14)	Poor	Mediocre
38	Encapsulate (54)	Fair (7)	Poor	Good
39	Encapsulate (48)	Poor (18)	Poor	Mediocre
40	Encapsulate (42)	Fair (6)	Good	Good

fibres found during SEM analysis were chrysotile fibres and no airborne amphibole fibre was detected.

DISCUSSION

The A algorithm takes into consideration the same parameters, detectable by direct visual inspection, as described in Ministerial Decree of 1994; each one of these is given a score in order to limit the variation caused by observer subjectivity.

The elements identified to indicate a potential fibre release refer to deterioration of the material (breakages, corrosion, cracks) and to both wind and rain damaging actions; the parameters to determine, therefore, refer to two distinct indicator types: roof condition indicators and fibre dispersion indicators.

In the evaluation criteria of this algorithm (Table 1), the roof condition indicators are outlined under the headings 'state of conservation', 'presence of cracks', and 'friability' and give one point margin between

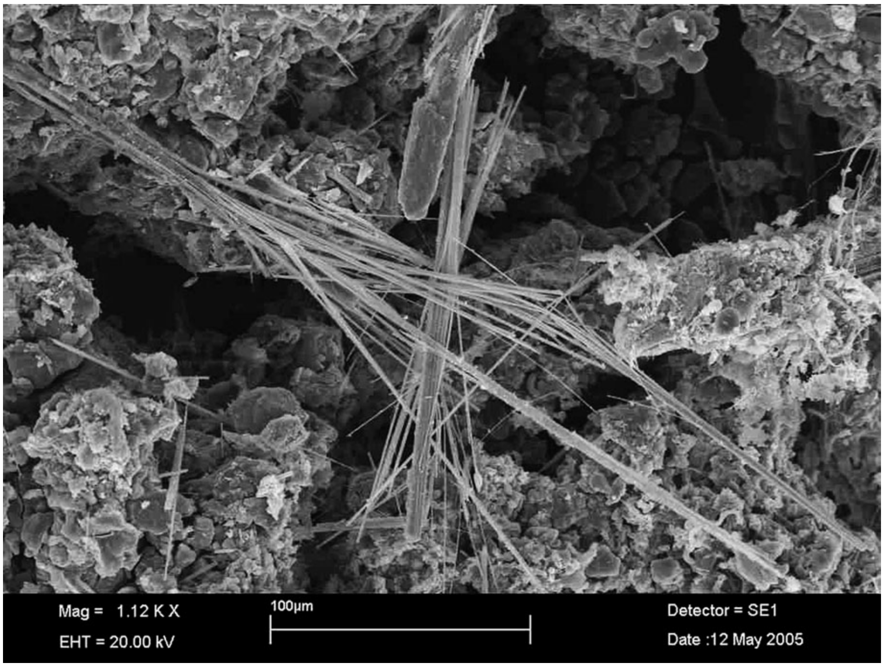

Fig. 5. SEM image of amosite fibres detached from an asbestos cement roof (state of conservation: very poor).

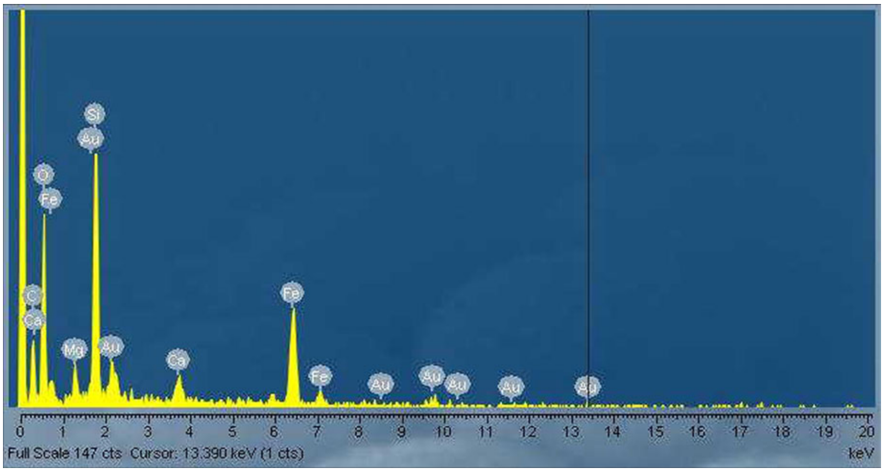

Fig. 6. EDS spectrum of amosite fibres.

the possible answers; the fibre dispersion indicators, on the other hand, are outlined under the headings 'surface release', 'support structure', 'distance from the windows', and 'frequency of access'; the closeness to windows or terraces is considered an important parameter and increases the score by three points with respect to those roofs situated at a distance from exits.

In the same way, particular attention was given to the 'type of asbestos'; three extra points were given to those roofs containing amphibole or mixed amphibole and chrysotile asbestos with respect to those containing only chrysotile.

Furthermore, particular importance was given to 'age', since in calculation of the final score, the points given due to ageing became a multiplicative factor and so weighed more heavily on the overall judgement.

The only critical point regarding the A algorithm was found in the evaluation of assessment parameter 'E', relative to surface release. It is very difficult to judge visually if particles of material stick to latex gloves after having rubbed them against the asbestos cement sample.

The B evaluation algorithm (Table 2) involves the evaluation of descriptive elements relating to the location and context in which the asbestos products are found, the type of sheets (flat or corrugated), the extension and inclination of the roof, the damage it has been subjected to, the year in which it was built, the

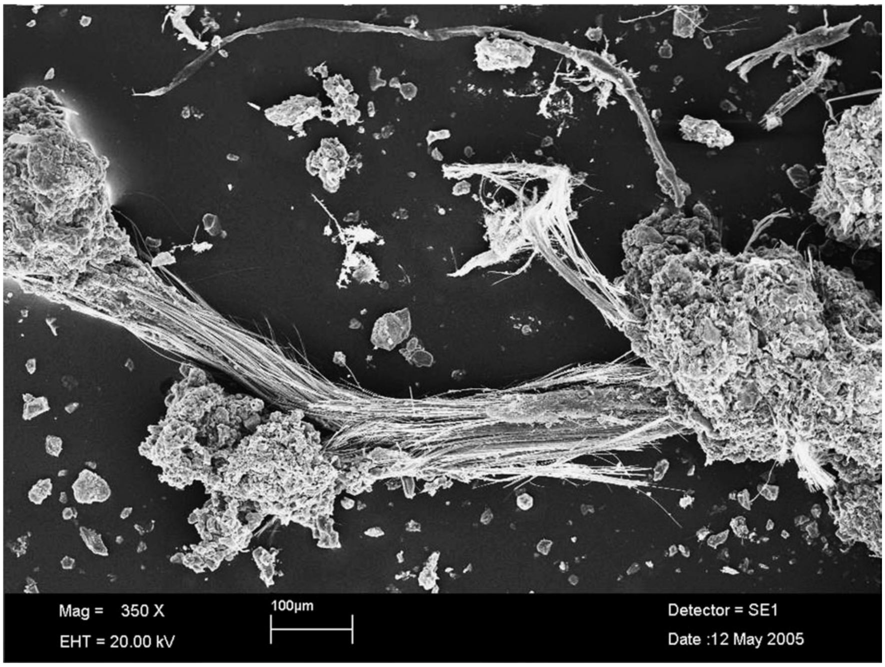

Fig. 7. SEM image of chrysotile fibres detached from an asbestos cement roof almost completely cement free (state of conservation: very poor).

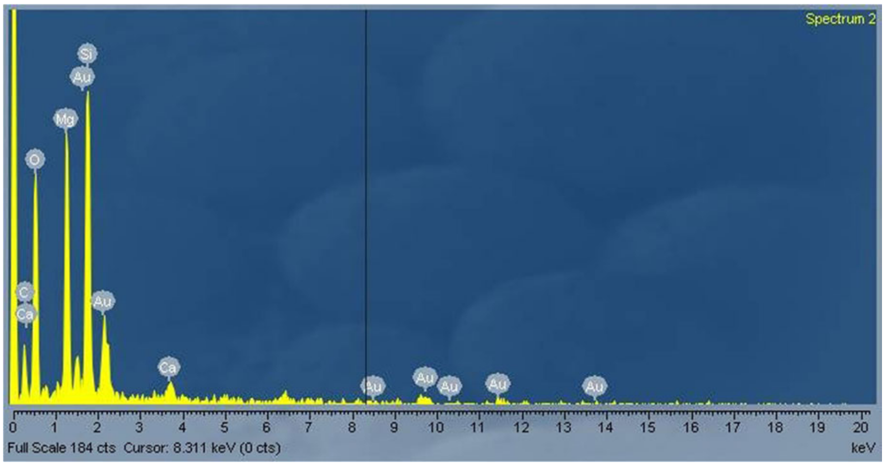

Fig. 8. EDS spectrum of chrysotile fibres.

presence of windows in the vicinity, and the presence of schools or nursing homes in the surrounding areas.

Also in this case, the discovery indicators used in the visual inspections are based on those described by the Ministerial Decree of 1994.

The ‘material solidity’, ‘flaking’, ‘cracks’, and ‘breakages’ refer to indicators relating to the roofing conditions; the ‘appearance of fibres’ and ‘friable or pulverulent material in the gutter’, on the other hand, refer to fibre dispersion indicators.

The friable or pulverulent material in the gutter heading aims to quantify the concentration of powder and fibres in the samples taken from the gutters and dripping points and from the rainwater drainage areas. A 5% concentration of asbestos fibres is most often found in such samples, while higher concentrations indicate a worse state of conservation (it is not unusual to find the 40% concentrations). It is recognized that the evaluation of possible material found in the gutter depends on climatic events which could have taken place in the days running up to the sampling.

It is, however, necessary to point out that climatic variations can put the reliability of these data into question; indeed rain, wind, and other atmospheric agents can carry fibres causing significant changes to the data revealed in better weather conditions. Heavy rain can, indeed, completely remove the material accumulated in the gutter.

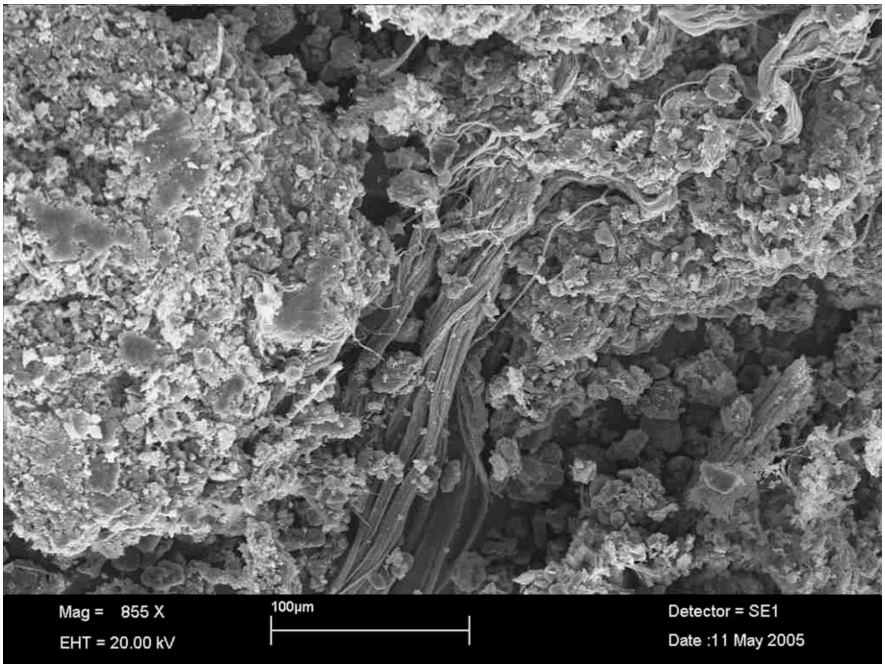

Fig. 9. SEM image of chrysotile fibres closely included in cement matrix (state of conservation: poor).

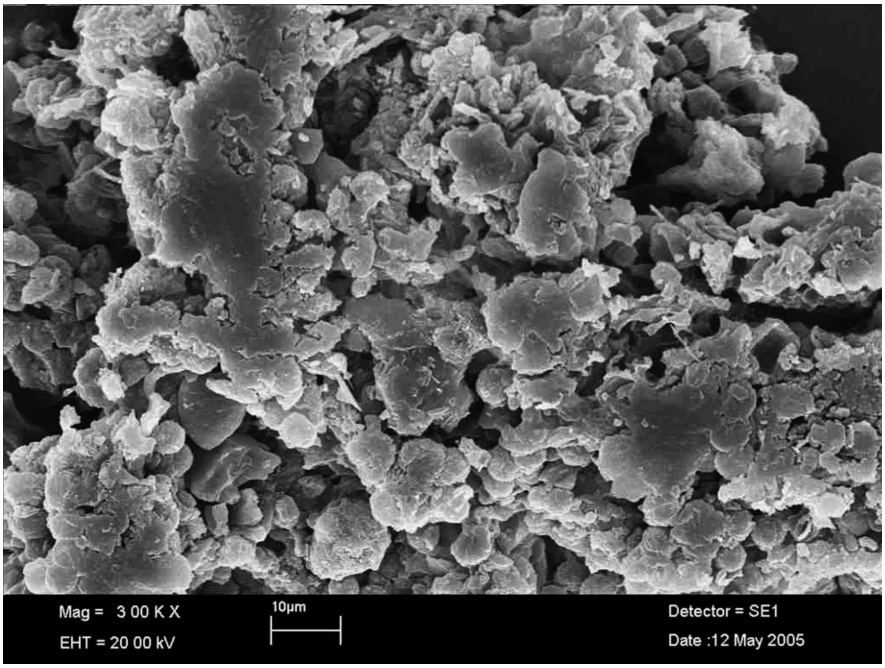

Fig. 10. SEM image of cement material detached from an asbestos cement roof (state of conservation: good).

Also the presence of stalactites that have formed from the aggregation of free fibres, plant-based residues, and earth, etc., along the dripping lines represents a further indication of potential fibre dispersion.

Furthermore, algorithm B does not take into account the two most important parameters, which are the type of asbestos used to make the manufactured article and if there are adjacent windows and terraces. These parameters are reference parameters for possible exposure to people and cannot be ignored in the risk evaluation and in expressing a judgement relative to possible intervention work to be undertaken. They mean that the A algorithm was certainly more comprehensive.

The final result of the B algorithm is obtained by simply making the sum of all the points given on the basis of the individual indicators.

Table 4. Mean airborne asbestos fibres concentration measured in adjacent areas to buildings with asbestos cement roofs

Building's typology	Investigated buildings	Air samplings	C_{mean} (f l^{-1})	λ_L (f l^{-1})	λ_U (f l^{-1})
Farms	5	13	0.4	0.1	1.0
Industrial sheds	4	10	0.4	0.1	1.0
Repair shops	2	4	0.4	0.1	1.0
Industrial disused sites	7	30	0.6	0.2	1.4
Public buildings	2	6	0.0	0.0	0.4

It can be immediately noted from Table 3 that the A algorithm has never given a score of <26 which corresponds to the maximum limit value allowed for leaving the material without it being subject to any form of treatment. Indeed, never having roofs of <10 years old, the score given is always high. Furthermore, it should be remembered that in the algorithm calculation, age becomes a multiplicative factor of the entire expression and so its importance becomes significant. On the contrary, using the B algorithm none of the roofs investigated is classified as very poor, indeed, the majority are classified as poor.

The pull-up test resulted as being fairly in agreement with the A algorithm since the roofs classified as 'very poor' by the former resulted as 'to be removed' with the latter; just as those classified as 'good' or 'poor' with the pull test corresponded with the need to 'encapsulate' according to the A algorithm. It is clear that since the UNI method has four classification groups (very good, good, poor, and very poor), it gives a higher probability of including more judgements in the wider classifications described by the algorithm.

CONCLUSION

The state of deterioration of 40 asbestos cement roofs was evaluated using two priority assessment algorithms elaborated in Italy and considered the most appropriate for our study. The results of this evaluation were compared with those obtained by the pull-up test and by the indicators defined by Italian regulation coupled with observations of a sample using stereomicroscopy. The results obtained associating the pull-up test with the A evaluation algorithm provided a reliable evaluation on roof deterioration.

It is, however, always important to train the operator conducting the study since a completely subjectivity-free method does not exist. Whatever method is used, whether it be an algorithm, the UNI method, or any other, it will always be affected by the subjectivity linked to the competency, the training, and other characteristics of the operator. Each method all alone cannot assess the risk of exposure to asbestos in any way but coupling more one method such as visual inspection, pull-up test, and A assessment algorithm can give a reliable assessment of ACM for sound decisions.

Finally, it is worth noting that when asbestos cement roofs in an advanced state of deterioration are found, such as that discussed in this study (Table 4), a significant release of asbestos fibres is not observed from such materials. We must consider, however, that an air sample gives the number of air-dispersed fibres at the time in which the sampling takes place, without giving any information regarding the possible prior release of fibres. The high quantity of asbestos fibres found in the material gathered from the gutters is testimony to the fact that a slow and continued release of asbestos fibres takes place from the material. In these cases, the biggest problem is the reuptake of such fibres in the environment.

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