CHEMICAL ENGINEERING TRANSACTIONS
VOL. 114, 2024

A publication of AIDIC
The Italian Association of Chemical Engineering
Online at www.cetjournal.it

Guest Editors: Petar S. Varbanov, Min Zeng, Yee Van Fan, Xuechao Wang

**ISBN** 979-12-81206-12-0; **ISSN** 2283-9216
DOI: 10.3303/CET24114119

# Analysing the Environmental Durability and Chrysotile Content of Asbestos Cement Products by FT-IR Spectroscopy

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The aim of this paper is to examine the environmental resistance and chrysotile content of different asbestos cement products and to prove the relationship between these two factors by analytical results. The paper includes Fourier-transform infrared (FT-IR) spectroscopic analysis of asbestos cement pipes and asbestos cement products with corrugated and flat characteristics. The methodology of the study is based on FT-IR spectroscopy and general statistical approaches, and the results obtained are compared using correlation analysis. The background to the topic is that asbestos cement products are still widely used today despite their harmful effects on health, contrary to European Union asbestos-free targets. A damaged and eroded asbestos cement product loses several grams of asbestos and cement per year from its matrix structure, which is exacerbated by exposure to various environmental influences. The match rate of the chrysotile spectrum for analysed samples has been over 50 % in each case. In the number of measurements, the chrysotile detection rate was 7.64 % higher for degraded and eroded samples. In addition, in the samples exposed to environmental factors, the percentage variance was approximately 10 % or higher, with the exception of asbestos cement pipes. The results provide a basis for situational awareness options. Analytic practitioners, material science researchers, and analysts can use them.

## 1. Introduction

Asbestos minerals are naturally occurring fibrous silicate minerals that have been used in a variety of insulating, refractory (Mahini, 2005), and construction materials because of their durable fibres and ability to withstand high temperatures. Asbestos is a collective term used to describe a group of naturally found fibrous minerals, either serpentine (chrysotile) or amphibole (actinolite, amosite, anthophyllite, crocidolite and tremolite) in nature (Mahini, 2005).
Chrysotile comprises approximately 95 % of naturally occurring asbestos and is the most widely used industrially (Zholobenko et al., 2021). It also constitutes over 90 % of asbestos in water samples. All asbestos types, including chrysotile and amphiboles (crocidolite, amosite, tremolite), are recognised as carcinogenic to human lungs, although chrysotile may exhibit lower carcinogenic potency (Boffetta, 2018). In Europe, asbestos fibres are defined as those longer than 5 µm, wider than 3 µm, and with an aspect ratio greater than 3:1 (Dichicco et al., 2017).
A defining trait of the relevant type is that when chrysotile fibres are disrupted, such as through grinding, crushing, or exposure to water, the structure of the chrysotile fibre disintegrates, and individual fibres are created (Bernstein and Hoskins, 2006). Chrysotile asbestos consists of a fibrous $Mg_3(Si_2O_5)(OH)_4$ arranged in a 1:1 ratio, with interconnected silica tetrahedra attached to a brucite-like trioctahedral sheet. This structural arrangement results in curvature, giving rise to the fibrous nature of chrysotile (Mendelovici et al., 2001).
The worldwide industrial use of asbestos has expanded quickly over the past 150 y due to its valued properties, such as conductivity, fire resistance, and reinforcement in construction and manufacturing (Furuya et al., 2018).

Paper Received: 19 May 2024; Revised: 10 October 2024; Accepted: 1 December 2024
Please cite this article as: Macher G.Z., Torma A., Beke D., 2024, Analysing the Environmental Durability and Chrysotile Content of Asbestos Cement Products by FT-IR Spectroscopy, Chemical Engineering Transactions, 114, 709-714 DOI:10.3303/CET24114119

Asbestos is currently prohibited in over 50 countries globally, but it continues to be extracted and utilised in numerous nations. The primary asbestos producers encompass the Russian Federation, China, Kazakhstan, Brazil, Canada, Zimbabwe, and Colombia (Frassy et al., 2014). Presently, it is estimated that illnesses related to asbestos exposure (Castiblanco et al., 2020) cause approximately 255,000 deaths annually (Furuya et al., 2018). Despite the considerable knowledge of the risks linked to asbestos, this hazardous material continues to pose a significant health risk on a global scale, leading to numerous annual fatalities and making a substantial contribution to cancer-related deaths. However, there is ongoing and increasing worry regarding the potential public health hazard presented by still-in-use asbestos-containing materials (abbreviation: ACM) and their possible influence on future cases of asbestos-related illnesses.

Asbestos-containing materials include flat and corrugated sheets for roofing and compressed panels for cladding and facades in residential structures (Krówczyńska et al., 2014). Asbestos cement (abbreviation: AC) slates are made by mixing 10-20 % chrysotile with 80-90 % cement (Jeong et al., 2013). While asbestos cement sheets are used for roofing and cladding, they are inherently brittle and prone to cracking from minor impacts, repetitive stress, or faulty fastenings (Bassani et al., 2007).

Exposure to asbestos remains a significant concern during the natural weathering, repair, or demolition of buildings with asbestos shingles. The deterioration of these materials releases asbestos fibres into the air and water runoff, leading to indirect soil contamination (Hikuwai et al., 2023). A study by Suzuki et al. (2005) indicates that a corrugated asbestos cement sheet can release several grams of asbestos annually from its matrix structure.

Standard techniques for identifying asbestos currently include using polarised light microscopy for analysing bulk samples and phase-contrast microscopy for examining airborne fibres (Zholobenko et al., 2021). In addition, optical microscopy, scanning electron microscopy, transmission electron microscopy, and scanning transmission electron microscopy are frequently utilised for identifying asbestos fibres in environmental and human samples (Janik and Wrona, 2005). Infrared spectroscopy is also a valuable technique for swiftly identifying various kinds of clay minerals (Farro et al., 2023), as well as detecting asbestos contamination and assessing its qualitative parameters (Wu et al., 2021), the Fourier-transform infrared (abbreviation: FT-IR) method has also been utilised for the characterisation of asbestos fibres by analysing their distinct silicate vibrational bands in the range of 900-1,200 $cm^{-1}$.

Analysing asbestos content using FT-IR spectroscopy is not a new approach. Previous studies have employed this technique to determine the presence (Giacobbe et al., 2010) and identify different types of asbestos (Zholobenko et al., 2021). However, the role of environmental factors in the detectability of asbestos content beyond its release has received limited attention. Our research aims to address this gap, providing a valuable contribution to the field.

## 2. Materials and methods

The paper seeks to explore the detectability of chrysotile and the environmental durability of asbestos cement products using FT-IR spectroscopy. This section outlines the principal research methods and parameters that were required for this paper.

### 2.1 Experimental materials and samples

Three categories of asbestos-containing materials samples were utilised: asbestos cement slates with corrugated characteristics, AC-flat slates, and AC pipes. Two subgroups were formed within each category: one was exposed to environmental elements (rain, wind, temperature, sunshine) with five samples, and one was shielded from these factors with another five samples. Measurements were repeatedly conducted on each sample to determine conformity with chrysotile spectra. The success of these matches was recorded, and a statistical analysis was performed based on the top 10 matches. This methodology facilitated the evaluation of how environmental exposure affects the integrity of these products compared to their preserved counterparts. The environmentally exposed samples were actual products obtained from demolition and usage, sourced from various sites in Győr. The separated samples were obtained from the same area, specifically from locations where unused asbestos cement products had been stored. The collected samples were hermetically stored until the commencement of the experiments. The investigation of environmental factors is theoretical, as the experiment does not employ a stress or pressure chamber. The research is predicated on the assumption that the samples in use have been continuously exposed to environmental influences, including ageing, damage, sunlight, and rain, among others.

The initial batch of samples consists of undulating AC-corrugated sheets. These samples, approximately 30-40 y old, displayed visible signs of erosion and degradation due to environmental exposure alongside various deposits. The samples' labelling exposed to environmental influences ranged from AC-S-E-1 to AC-S-E-5, with the mean value being labelled as AC-S-E-A. The labelling of separated samples ranged from AC-S-S-1 to AC-S-S-5, with the mean value being labelled as AC-S-S-A.

The second set comprises flat AC sheets with similar ageing (approximately 40 y), which exhibited comparable effects from environmental influences. The samples' labelling exposed to environmental influences ranged from AC-F-E-1 to AC-F-E-5, with the mean value being labelled as AC-F-E-A. The labelling of separated samples ranged from AC-F-S-1 to AC-F-S-5, with the mean value being labelled as AC-F-S-A.

Lastly, the third group includes AC pipes with characteristics consistent with those mentioned earlier. The samples' labelling exposed to environmental influences ranged from AC-P-E-1 to AC-P-E-5, with the mean value being labelled as AC-P-E-A. The labelling of separated samples ranged from AC-P-S-1 to AC-P-S-5, with the mean value being labelled as AC-P-S-A.

Before conducting the analysis, all three sets of samples were meticulously cleaned with distilled water and isopropyl alcohol to remove any possible impurities that could impact the findings. Following this step, they were then cut into consistent sizes before being encased in a multi-component epoxy resin.

### 2.2 Sample preparation

The specimens underwent a cleaning process using distilled water, which may have affected the investigation of environmental influences. Epoxy resin was poured into a mould according to specified dimensions to create discs measuring 30 x 5 mm. These discs were then ground with a grinder to achieve the desired size and subsequently placed on an instrument slide for examination. A 0.3-mm diamond crystal facing downwards allowed for the scanning of specific areas in the sample with infrared rays, resulting in the generation of an absorption map showing different spectra marked by varying colours. These coloured spectra corresponded to materials in the spectrum library, facilitating component identification.

### 2.3 Analysis of chrysotile asbestos by FT-IR spectroscopy

All types of asbestos display strong absorption in the 1,200-900 $cm^{-1}$ and 600-300 $cm^{-1}$ ranges. Qualitative identification of the asbestos type can be achieved by analysing the spectrum up to 200 $cm^{-1}$. Chrysotile exhibits distinct differences from amphiboles, as it demonstrates significant double hydroxyl groups at 3,693 $cm^{-1}$ and 3,648 $cm^{-1}$, which are created between layers of hydroxyl groups situated within the primary silicate layers of the lattice.

### 2.4 Used instrument: PerkinElmer Spectrum 400

The PerkinElmer Spectrum 400 instrument from PerkinElmer, MA, U.S. was utilized for conducting measurements. The samples taken from fractured sections of asbestos cement products and collected scrap samples from the matrix material were analysed for their composition, particularly to identify any additives present. Following this step, these materials were placed on the object table of the spectroscope with a 0.3-mm diamond crystal facing upwards and secured in place with a force approximately equivalent to 100 N for analysis. These tests were sensitive to moisture and carbon dioxide. Thus, prior to each measurement, it was necessary to record the spectrum of the environmental background first in order for the instrument to differentiate between the true sample spectrum and background interference.

## 3. Results

### 3.1 Detection of chrysotile asbestos from asbestos cement corrugated sheets

The asbestos cement corrugated sheet samples have shown an average chrysotile asbestos detection rate of 0.747193 (1) under environmental exposure (Figure 1). The most significant match (0.810265 (1)) was recorded at the fourth measuring point for sample AC-S-E-5, while the lowest detection value (0.689985 (1)) was identified at the sixth measuring point for sample AC-S-E-4. Among the samples, the highest chrysotile detection average value (0.754616 (1)) was observed in the case of AC-S-E-2, whereas the lowest (0.742706 (1)) was found in AC-S-E-4. The asbestos cement corrugated sheet samples have shown an average chrysotile asbestos detection rate of 0.645437 (1) according to separated samples. The most significant match (0.701221 (1)) was recorded at the fourth measuring point for sample AC-S-S-4, while the lowest detection value (0.569845 (1)) was identified at the eighth measuring point for sample AC-S-S-5. Among the samples, the highest chrysotile detection average value (0.678396 (1)) was observed in the case of AC-S-S-1, whereas the lowest (0.605309 (1)) was found in AC-S-S-5. The overall rate of comparison within the entire sample series is 115.8 %. The average deviation from the mean is 0.00634 (1) for the exposed samples. In contrast, for the separated samples, this value is 0.00429 (1). Asbestos cement corrugated sheet samples exhibit a noticeable difference in spectral matching for chrysotile exposed to the environment (E), displaying higher values with an average of approximately 0.75 (1). Conversely, samples separated from environmental influence (S) demonstrate greater variability in values, with a central tendency around 0.65 (1). The analysed samples are based on an asbestos-cement matrix. Therefore, a wide peak was detected at 1,400 $cm^{-1}$ in the spectra. This can be attributed to the presence of calcium silicate hydrate, calcium sulphate, and calcium carbonate found in the cement mixture, specifically related to the stretching vibrations of C-O bonds. Similar to the findings in Foresti et al. (2003), there are two specific regions of the spectrum that are noteworthy: the O-H stretching vibrations contribute to the 3,700-3,500 $cm^{-1}$ region, while various lattice vibrations account for the bands observed in the 1,200-500 $cm^{-1}$ region.

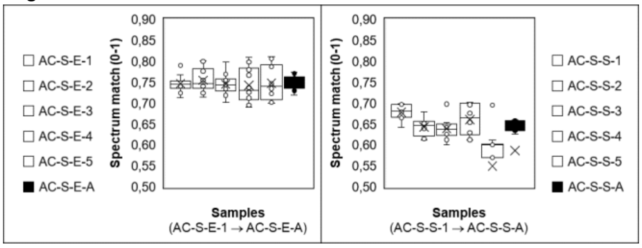


*Figure 1: Comparative analysis of chrysotile detection for exposed (E) and separated (S) samples (asbestos cement corrugated sheets)*

Asbestos cement corrugated sheet samples exhibit a noticeable difference in spectral matching for chrysotile exposed to the environment (E), displaying higher values with an average of approximately 0.75 (1). Conversely, samples separated from environmental influence (S) demonstrate greater variability in values, with a central tendency around 0.65 (1). The analysed samples are based on an asbestos-cement matrix. Therefore, a wide peak was detected at 1,400 $cm^{-1}$ in the spectra. This can be attributed to the presence of calcium silicate hydrate, calcium sulphate, and calcium carbonate found in the cement mixture, specifically related to the stretching vibrations of C-O bonds.

### 3.2 Detection of chrysotile asbestos from asbestos cement flat sheets

The asbestos cement flat sheet samples have shown an average chrysotile asbestos detection rate of 0.753552 (1) under environmental exposure. The most significant match (0.820001 (1)) was recorded at the tenth measuring point for sample AC-F-E-3, while the lowest detection value (0.694962 (1)) was identified at the second measuring point for sample AC-F-E-1. Among the samples, the highest chrysotile detection average value (0.773262 (1)) was observed in the case of AC-F-E-4, and the lowest (0.723031 (1)) was found in AC-F-E-1. Figure 2 illustrates a contrast in the chrysotile detection results for asbestos cement flat sheets according to the exposed or separated character.

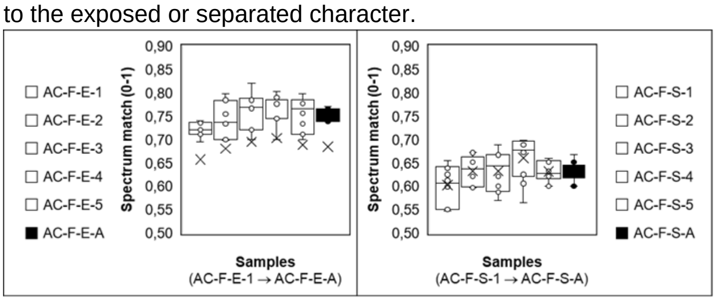


*Figure 2: Comparative analysis of chrysotile detection for exposed (E) and separated (S) samples (asbestos cement flat sheets)*

The asbestos cement flat sheet samples have shown an average chrysotile asbestos detection rate of 0.632309 (1) according to separated samples. The most significant match (0.698857 (1)) was recorded at the fifth measuring point for sample AC-F-S-4, while the lowest detection value (0.548113 (1)) was identified at the fourth measuring point for sample AC-F-S-1. Among the samples, the highest chrysotile detection average value (0.660611 (1)) was observed in the case of AC-F-S-4, whereas the lowest (0.602867 (1)) was found in AC-F-S-1. The overall rate of comparison within the entire sample series is 119.2 %. The average deviation from the mean is 0.00540 (1) for the exposed samples. In contrast, for the separated samples, this value is 0.00801 (1). The environmentally exposed (E) asbestos cement flat sheet samples exhibit a more noticeable difference in spectral matching for chrysotile. Chrysotile was more readily identifiable and had a higher agreement rate in the samples that were exposed to environmental effects. Conversely, samples separated from environmental influence (S) demonstrate greater variability in values, with a central tendency of less than 0.65 (1). Characteristic peaks of the chrysotile were identified at 3,700-3,500 $cm^{-1}$ and 1,200-500 $cm^{-1}$ ranges. The analysed samples are based on an asbestos-cement matrix; therefore, a wide peak was detected at 1,400 $cm^{-1}$ in the spectra, similar to the asbestos cement corrugated sheets.

### 3.3 Detection of chrysotile asbestos from asbestos cement pipes

The asbestos cement pipe samples have shown an average chrysotile asbestos detection rate of 0.800607 (1) under environmental exposure. The most significant match (0.888831 (1)) was recorded at the fifth measuring point for sample AC-P-E-4, while the lowest detection value (0.742121 (1)) was identified at the eighth measuring point for sample AC-P-E-2. Among the samples, the highest chrysotile detection average value (0.811325 (1)) was observed in the case of AC-P-E-3, and the lowest (0.793972 (1)) was found in AC-P-E-4. Figure 3 illustrates a contrast in the chrysotile detection results for asbestos cement pipes according to the exposed or separated character. The asbestos cement pipe samples have shown an average chrysotile asbestos detection rate of 0.794369 (1) according to separated samples. The most significant match (0.865548 (1)) was recorded at the seventh measuring point for sample AC-P-S-2, while the lowest detection value (0.724580 (1)) was identified at the ninth measuring point for sample AC-P-S-3. Among the samples, the highest chrysotile detection average value (0.808812 (1)) was observed in the case of AC-P-S-2, whereas the lowest (0.775610 (1)) was found in AC-P-S-4. The overall rate of comparison within the entire sample series is 100.8 %. The average deviation from the mean is 0.00617 (1) for the exposed samples. In contrast, for the separated samples, this value is 0.00438 (1).

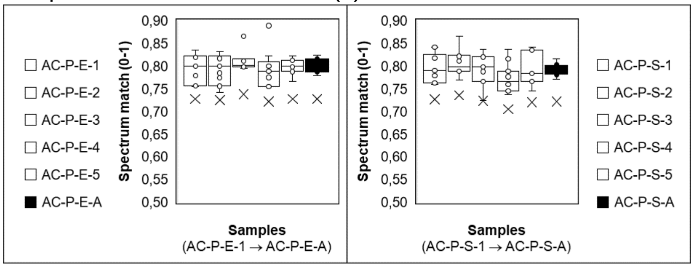


*Figure 3: Comparative analysis of chrysotile detection for exposed (E) and separated (S) samples (asbestos cement pipes)*

The environmentally exposed (E) asbestos cement pipe samples exhibit a more noticeable uniformity in spectral matching for chrysotile. Chrysotile was more easily detected and showed higher consistency in samples exposed to environmental conditions. The trend revolved around 0.80 (1) for the exposed samples (E) and about 0.79 (1) for the separated samples (S). The chrysotile displayed distinctive peaks at wavelengths of 3,700-3,500 $cm^{-1}$ and 1,200-500 $cm^{-1}$. As the analysed samples are composed of an asbestos cement mixture, a broad peak was observed at 1,400 $cm^{-1}$ in the spectra.

## 4. Conclusions

The research aims to assess the environmental impact and detectability of chrysotile asbestos in various asbestos cement products, such as flat and corrugated sheets and pipes, particularly focusing on samples shielded from environmental factors. It demonstrates that FT-IR spectroscopy is effective for identifying chrysotile asbestos by pinpointing characteristic spectral features. This method could become a standard for detecting chrysotile, given its accuracy and practicality. However, the presence of both chrysotile and the cement matrix complicates qualitative analysis. Notable variations were found between exposed (E) and separated (S) samples in corrugated and flat sheets, though less so in pipes.

The main findings of the research include: 1) FT-IR spectroscopy can be used for chrysotile detection and should be standardised in the future; 2) Chrysotile was more detectable in samples exposed to environmental conditions, with matching coefficients consistently around or above 0.75 (1); 3) Environmental impacts like erosion, degradation, product ageing, and corrosion contribute to the easier release and detectability of chrysotile asbestos.

The paper suggests that environmental conditions and ageing play a significant role in the release and detectability of chrysotile asbestos from asbestos cement products. Understanding these factors is essential for evaluating the environmental impact and health hazards linked to asbestos cement products and should be considered in forthcoming assessments. Continuing and expanding this analysis in the future is crucial, and its findings can benefit environmental and analytical researchers.

**Nomenclature**

FT-IR spectroscopy – Fourier-transform infrared spectroscopy
ACM – asbestos containing materials
AC – asbestos cement

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