Journal of Hazardous Materials 344 (2018) 981–993

Contents lists available at ScienceDirect

Journal of Hazardous Materials

journal homepage: www.elsevier.com/locate/jhazmat

Asbestos containing materials detection and classification by the use of hyperspectral imaging

Giuseppe Bonifazi, Giuseppe Capobianco, Silvia Serranti*

Department of Chemical Engineering, Materials & Environment, Sapienza University of Rome, Via Eudossiana 18, 00184 Rome, Italy

HIGHLIGHTS

- Innovative hyperspectral imaging based approach for asbestos fibers detection.
- Asbestos fibers identification and classification obtained coupling HSI with chemometrics.
- No sample preparation required, differently from classical analytical techniques.
- The proposed HSI approach can be applied both "in situ" and/or at "laboratory scale".
- The technique is environmental and safety friendly.

ARTICLE INFO

Article history:
Received 19 July 2017
Received in revised form
27 November 2017
Accepted 28 November 2017
Available online 29 November 2017

Keywords:
Asbestos
Mineral fibers
Construction materials
Hyperspectral imaging
Micro X-ray fluorescence

ABSTRACT

In this work, hyperspectral imaging in the short wave infrared range (SWIR: 1000–2500 nm) coupled with chemometric techniques was evaluated as an analytical tool to detect and classify different asbestos minerals, such as amosite ($(Fe^{2+})_2(Fe^{2+},Mg)_5Si_8O_{22}(OH)_2)$), crocidolite ($Na_2(Mg,Fe)_6Si_8O_{22}(OH)_2$) and chrysotile ($Mg_3(Si_2O_5)(OH)_4$), contained in cement matrices. Principal Component Analysis (PCA) was used for data exploration and Soft Independent Modeling of Class Analogies (SIMCA) for sample classification. The classification model was built using spectral characteristics of reference asbestos samples and then applied to the asbestos containing materials. Results showed that identification and classification of amosite, crocidolite and chrysotile was obtained based on their different spectral signatures, mainly related to absorptions detected in the hydroxyl combination bands, such as Mg-OH (2300 nm) and Fe-OH (from 2280 to 2343 nm). The developed SIMCA model showed very good specificity and sensitivity values (from 0.89 to 1.00). The correctness of classification results was confirmed by stereomicroscopic investigations, based on different color, morphological and morphometrical characteristics of asbestos minerals, and by micro X-ray fluorescence maps, through iron (Fe) and magnesium (Mg) distribution assessment on asbestos fibers. The developed innovative approach could represent an important step forward to detect asbestos in building materials and demolition waste.

1. Introduction

Asbestos is the common name used for two families of fibrous minerals, different for crystal and chemical characteristics: serpentine (i.e. chrysotile) and amphiboles (i.e. crocidolite, amosite, anthophyllite, actinolite and tremolite) [1,2]. They can all exist in several different crystalline forms, but only if characterized by a fibrous structure they are classified as asbestos. The most used mineral in the industrial sector is chrysotile, as it is contained in almost 95% of all asbestos products and/or artifacts. Among the amphiboles the most widely used mineral is crocidolite, followed by amosite [3].

Asbestos has been widely used in many applications for its technical properties, in particular for its resistance to abrasion, heat and chemicals [4,5]. However, despite its properties, asbestos is recognized as a hazardous material to human health and since 1980 it has been banned in many industrialized countries. Asbestos containing materials (ACMs) are potentially dangerous because of degradation/alteration effects, occurring in the ACMs matrices. As a consequence, ACMs become "brittle" and they can release fibers whose harmfulness is well known [6], whether inhaled [7] or ingested [8]. Furthermore, asbestos can also naturally occur, not only in large exploitable deposits, event quite rare, but also in rocks where, even if it is present as an accessory mineral, it constitutes a serious problem to face when some specific actions have to be carried out (i.e. opening and excavation, perform tunneling operations, etc.) [9].

* Corresponding author.
E-mail address: silvia.serranti@uniroma1.it (S. Serranti).

https://doi.org/10.1016/j.jhazmat.2017.11.056

Table 1
Comparison among the pure asbestos fiber samples assumed as reference performed by micro X-ray fluorescence and those resulting from literature [31].

	Series	Norm. wt. (%)	Error wt. (%) (Sigma)	Literature values wt. (%)
Amosite				
Silicon	K-series	22.63	0.129175	22.43
Oxygen	–	37.88	–	38.34
Iron	K-series	33.69	0.033218	39.03
Hydrogen	–	0.72	–	0.20
Manganese	K-series	2.44	0.000204	–
Magnesium	K-series	2.64	0.003509	–
Chrysotile				
Silicon	K-series	19.55	0.460419	20.27
Oxygen	–	51.25	–	51.96
Iron	K-series	1.71	0.000352	–
Hydrogen	–	1.12	–	1.45
Manganese	K-series	0.05	0.000001	–
Magnesium	K-series	26.32	0.644506	26.21
Crocidolite				
Silicon	K-series	23.46	0.221071	24.01
Oxygen	–	39.97	–	41.03
Iron	K-series	28.53	0.036248	29.84
Hydrogen	–	0.61	–	0.22
Manganese	K-series	0.05	8.8E-07	–
Magnesium	K-series	2.31	0.004392	–
Sodium	K-series	5.07	0.084851	4.91

The exposition of people to asbestos is quite huge. World Health Organization (WHO) report shows as about 125 million people are exposed to asbestos at the workplace. Every year, asbestos-related-tumors produce the death of about 100,000 people, several thousand related to asbestos exposure at home.

Legislation around the world has not only limited the extraction and use of asbestos, but has also provided for the obligation of the removal of thousands of tons of ACMs [10]. However, it is extremely complex to identify ACMs considering that they have been used in more than 3000 different types industrial applications [11,12].

Several solutions were explored to clean up ACMs [13–16] but first of all a preliminary separation of contaminated products from non-hazardous waste is required. Additionally, fiber identification techniques are crucial for environmental control in contaminated areas such as the proximity of an asbestos mine [17,18].

The possibility to adopt fast and reliable analysis methods to detect and identify asbestos fibers, during the demolition or renovation of a building, is of great interest in terms of safety, time and costs. Hyperspectral imaging (HSI) based systems are widely used in remote sensing (i.e. satellite, aerial platform and drones) to identify and map specific aspects of the territory, including the presence of hazardous materials, as the ACMs in rural, mountains, industrial and urban areas [19–23]. Several modelling strategies have been set up and utilized for the identification of asbestos–cement roofing [24,25]. Limitations for ACMs mapping using HSI include lack of suitable spectral libraries for urban materials, presence of shadows, non-roof coverage elements and spectral similarities, etc. [26–28].

In this work, HSI was applied to classify ACMs at laboratory scale, according to the promising results obtained in our previous studies [29,30]. To our knowledge, no other studies are published on the utilization of HSI for asbestos and ACMs classification at laboratory scale.

The proposed strategy, based on the combined use of HSI and chemometric techniques can be a valid and efficient analytical approach that can support, and sometimes replace, the currently adopted techniques for asbestos recognition, such as Fourier transform infrared spectroscopy (FT-IR) [31], Raman spectroscopy [32,33], polarized light microscopy (PLM) [34] and scanning electron microscopy (SEM) [35,36]. All these techniques require the physical collection and preparation of samples and usually allow punctual measurements and/or small areas mapping. HSI, on the contrary, does not require any sample preparation, thus allowing the acquisition of large quantities of samples in shorter time.

Table 2
Asbestos samples selected to perform the HSI based recognition/classification procedures.

Sample	Asbestos mineral	Description
F1	Chrysotile	Rope
AM1	Chrysotile and crocidolite	Fragment of asbestos cement panel
AM2	Amosite	Fragment of fibers based panel
AM3	Amosite	Fragment of plaster embedding fibers
AM4	Crocidolite	Fragment of a water tank
AM5	Chrysotile and crocidolite	Fragment of asbestos cement panel

The aim of the proposed work was to apply HSI technique for detection and classification of different asbestos minerals, embedded in different matrices of "humans manufactured" products in the construction sector. The spectral range utilized to reach these goals is the **S***hort* **W***ave* **I***nfra***R***ed* (SWIR: from 1000 to 2500 nm), the same utilized for the analysis carried out by remote sensing [37,38].

The investigated ACM samples were preliminarily analyzed by optical microscopy to identify both asbestos fibers and matrix, to better understand the potentialities and the limits of the HSI approach.

The acquired images of ACM samples were processed using chemometric techniques, in order to operate an automatic classification of asbestos fibers. To assess the quality of predictions obtained by HSI, the same areas were acquired by micro X-ray fluorescence (micro-XRF) to map the chemical elements distribution with reference to the different types of asbestos and to compare them with those generated by hyperspectral modeling.

2. Materials and methods

2.1. The investigated samples

2.1.1. Reference asbestos samples

Three pure asbestos samples, provided by VERAM srl (Rome, Italy), were selected to create the reference data set utilized for calibration and modelling, that is a sample of amosite: $(Fe^{2+})_2(Fe^{2+},Mg)_5Si_8O_{22}(OH)_2)$ (Fig. 1a), a sample of chrysotile: $Mg_3(Si_2O_5)(OH)_4$ (Fig. 1b) and a sample of crocidolite: $Na_2(Mg,Fe)_6Si_8O_{22}(OH)_2$ (Fig. 1c).