

Analysis of asbestos-containing materials by light microscopy

Asbestos is known to cause serious lung conditions and is therefore under strict regulation. In the United Kingdom, the Control of Asbestos Regulations (CAR 2006) require only a qualitative test to describe a material as containing asbestos. They define asbestos as the fibrous forms of several naturally occurring silicate minerals that have been exploited for their useful properties of flexibility, high tensile strength, incombustibility, low thermal conductivity, and resistance to chemical attack. Asbestos is ideally suited for analysis by light microscopy as it has specific optical properties that distinguish it from other minerals.

The asbestos materials are: chrysotile, crocidolite, amosite, asbestos anthophyllite, asbestos actinolite or asbestos tremolite, or any mixture of them (see Table 1). In the UK chrysotile, amosite and crocidolite have been used in over 3000 different products, and are commonly found in pre-1999 buildings.

Asbestos minerals (like many other silicate minerals) have a crystal lattice structure based on a regular three dimension array of silica tetrahedra, with a number of various cations making up the structure. The exact arrangement of the tetrahedra and the identity of the cations affect the interactions between the crystal structure and the light rays transmitted through it, and thus determine the observable optical properties.

The microscopy of asbestos

A low-powered stereo microscope (*e.g.*, $\times 8$ to $\times 40$ magnification) is required for the initial search for fibres. A polarised light microscope with Köhler (or Köhler type) illumination is then needed for their identification. This microscope should be equipped with either dispersion staining or phase contrast objectives to enable the refractive indices (RIs) of the fibres to be determined.

Laboratories undertaking this type of work must hold reference samples of the six asbestos types and the commonly-occurring non-asbestos fibres. These include natural organic fibres (such as cotton and hair), synthetic organic fibres (such as aramid, polyester and rayon), man-made mineral fibres (for example, mineral wool and glass fibre), and naturally occurring mineral ‘fibres’ (such as wollastonite (CaSiO_3) and diatom fragments.



Figure 1. Asbestos tremolite fibres under scanning electron microscopy

A number of observation modes are required to determine the optical properties of an unknown fibre. They are obtained by inserting various accessories into the light path to create different interactions between the light rays and the particles under study. The different optical properties thus assessed are compared for identification with those of known types of asbestos. Asbestos fibres show a more limited range of optical properties than other minerals, because of their extreme growth along the *c*-axis and the presence of many fine fibres in more or less parallel alignments. These characteristics, along with the frequent occurrence of twinning, ensure that fibres will have a preferential alignment in the microscope—it is not possible to look down the end of the fibre and observe the optical effects in that orientation.

Table 1 Asbestos varieties. The CAS number is the number in the register of the Chemical Abstracts Service.

Asbestos Variety	CAS Number	Non-asbestos mineral analogue	Nominal composition
Chrysotile	12001-29-5	Lizardite, Antigorite	$\text{Mg}_3(\text{Si}_2\text{O}_5)(\text{OH})_4$
Crocidolite	12001-28-4	Riebeckite	$\text{Na}_2\text{Fe}_3^{2+}\text{Fe}_2^{3+}(\text{Si}_8\text{O}_{22})(\text{OH})_2$
Amosite Asbestos grunerite	12172-73-5	Grunerite	$(\text{Fe}^{2+}, \text{Mg})_7(\text{Si}_8\text{O}_{22})(\text{OH})_2$
Asbestos anthophyllite	77536-67-5	Anthophyllite	$(\text{Mg}, \text{Fe}^{2+})_7(\text{Si}_8\text{O}_{22})(\text{OH})_2$
Asbestos actinolite	77536-66-4	Actinolite	$\text{Ca}_2(\text{Fe}^{2+}, \text{Mg})_5(\text{Si}_8\text{O}_{22})(\text{OH})_2$
Asbestos tremolite	77536-68-6	Tremolite	$\text{Ca}_2\text{Mg}_5(\text{Si}_8\text{O}_{22})(\text{OH})_2$

Exploiting the optical properties

An assessment of the optical properties of a fibre is carried out in the following sequence.

- Under polarised light conditions the morphology, colour and pleochroism (colour in relation to the orientation of the polarised light) can be observed. Crocidolite appears blue (parallel) and grey (perpendicular). Other asbestos types are less pleochroic, with actinolite usually pale green (parallel) and amosite light brown.
- The analyser is then inserted (to give crossed-polarisers) and the stage is rotated to observe birefringence and the extinction characteristics. Asbestos-like fibres have parallel extinction (*i.e.*, they go dark). They exhibit maximum birefringence (*i.e.*, brightness) when the polarisers are at 45°. Different asbestos types have characteristic degrees of birefringence.
- With the polarisers still crossed, a first-order red compensator is inserted and the stage is rotated to determine the sign of elongation. All the asbestos types are 'length slow' (*i.e.*, the maximum retardation of the light is along the fibre's length), except crocidolite, for which the maximum retardation is across the fibre.
- The RIs of the fibre are assessed by dispersion staining to see whether the values are typical and consistent with published data. This is achieved by observing the dispersion colours at the interface between the fibre and the RI liquid. The most commonly used techniques require that the analyser and compensator be withdrawn, the illumination increased, and an objective with a central stop or phase ring in the back focal plane be inserted together with an appropriate condenser stop.

A close match between the optical properties of the unknown fibre and the asbestos standard would normally be achieved. Further representative fibres would need to be analysed if the observations were inconclusive, or if more than one type of fibre were found.

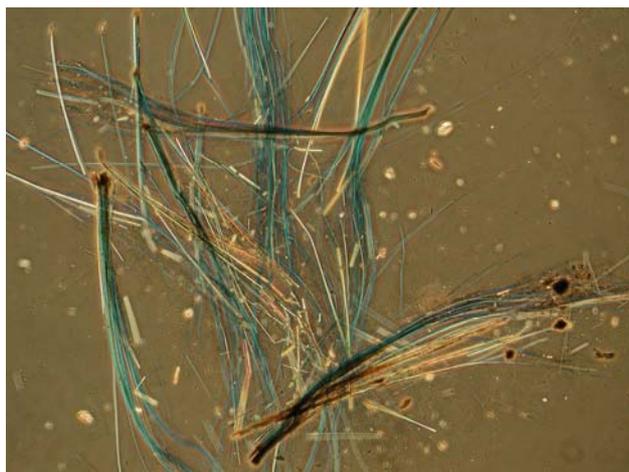


Figure 2. Crocidolite fibres under crossed polarisers, showing interference colours (birefringence) and parallel extinction, $\times 125$ magnification.

Detection power

With careful application of this method, a single asbestos fibre may be found in a few milligrams of dispersed material. In principle, a fibre 100 μm long by 2 μm diameter implies a detection limit of about 1 ppm mass fraction. In practice, the detection limit will be higher, as there are several matrix-dependent factors that complicate the detection and identification of asbestos fibres. While microscopy provides a very sensitive test, it relies on a subjective assessment of colour changes and effects. It therefore calls on careful quality control and quality assurance (accreditation, proficiency testing etc) to maintain the integrity of the analysis and minimise false positive and false negative results.

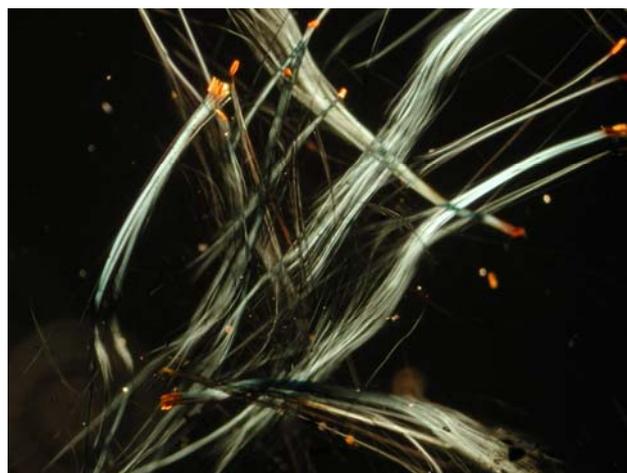


Figure 3. Crocidolite fibres showing blue dispersion staining colours in a liquid of refractive index 1.700 and with phase-contrast conditions, at $\times 125$ magnification.

Further Reading

- *Asbestos: The analyst's guide for sampling, analysis and clearance procedures.* HSG248, HSE Books 2005. ISBN 0 7176 2875 2.
- *Work with materials containing asbestos. Control of Asbestos Regulations 2006, Approved Code of Practice and guidance.* L143, HSE Books 2006. ISBN 0 7176 6206 3.
- *Surveying, sampling and assessment of asbestos-containing materials.* MDHS 100. HSE books 1994. ISBN 0 7176 0677 5

This Technical Brief was drafted for the Analytical Methods Committee by Barry Tylee of the Health and Safety Laboratory.

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